Proceedings of the

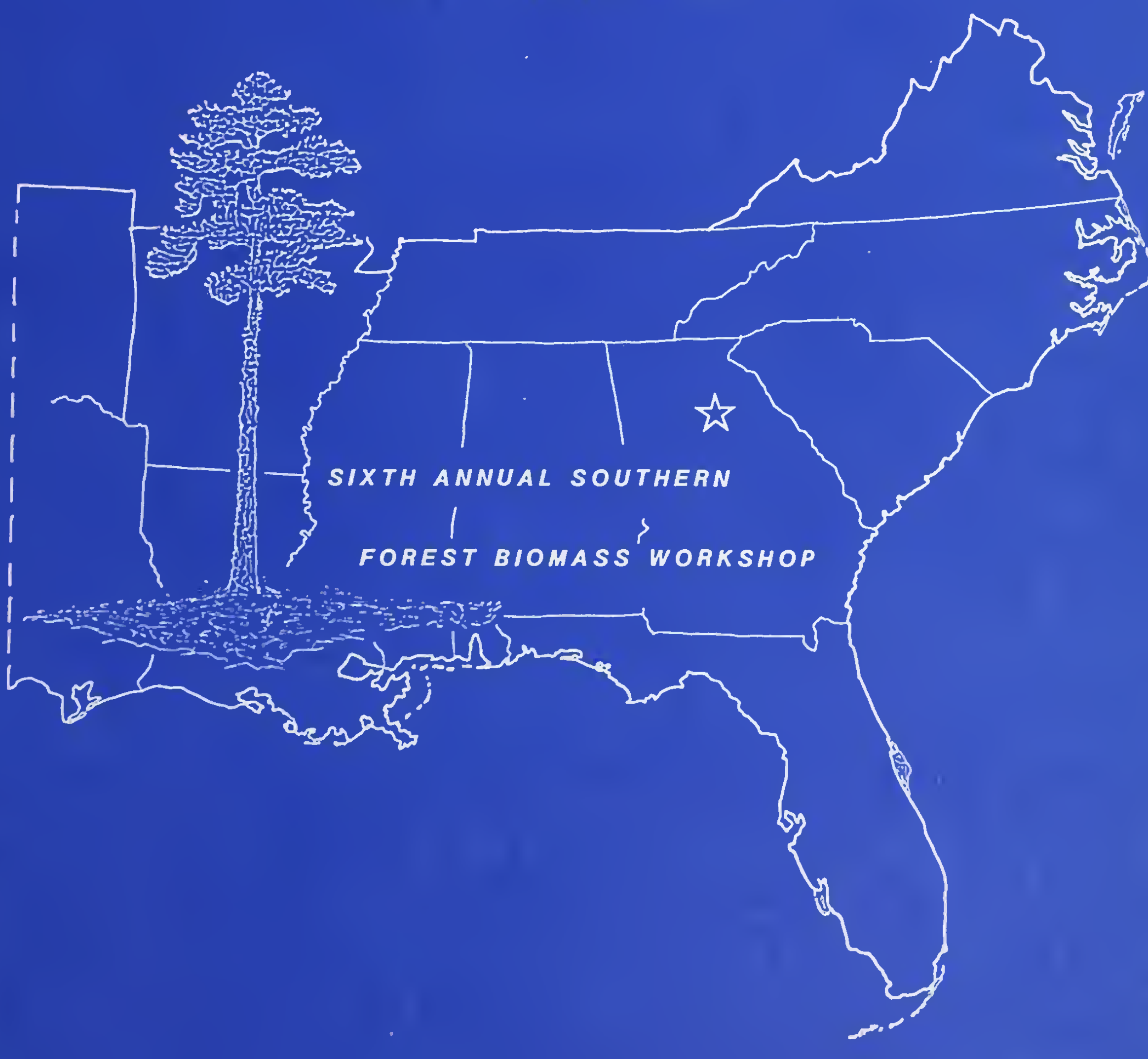
1984

SOUTHERN FOREST BIOMASS WORKSHOP

Athens, Georgia

June 5-7, 1984

Edited by Joseph R. Saucier



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Sixth Annual Meeting of the Southern Forest Biomass Working Group

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FOREWORD

The Sixth Annual Meeting of the Southern Forest Biomass Working Group was held June 5-7, 1984, in Athens, Georgia. The meeting was hosted by the Southeastern Forest Experiment Station and the University of Georgia, School of Forest Resources.

The Southern Forest Biomass Working Group was organized for the purpose of providing a forum for (1) exchange of information among researchers and practitioners in the areas of biomass sampling, measurement, harvesting and utilization, (2) review of research in progress, (3) research coordination and establishment of working relationships, and (4) to provide a sounding board for new approaches or techniques of general interest.

This year's meeting deviated somewhat from past meetings. In conjunction with, but preceding the Workshop, the University of Georgia, School of Forest Resources, hosted a forum in which leaders from government and industry reviewed programs and policies that guide the development of forest biomass for energy. Written texts of the forum presentations are published in these Proceedings with exception of the presentation by Dr. Beverly J. Berger, Department of Energy, which was not made available.

Likewise, five presentations in the Workshop were not available for inclusion in these Proceedings. The Planning Committee expresses appreciation to Charles Thomas, Klaus Steinbeck, Michael Taras, Carrol Cochran and Timothy Ku for their participation and contribution to a successful meeting.

Recognition is given to Dr. Leon A. Hargreaves, Jr., Dean, University of Georgia, School of Forest Resources, and Dr. Eldon W. Ross, Director, Southeastern Forest Experiment Station, for their interest and support of the meeting. Recognition is also given to the program moderators for their outstanding job of conducting an excellent meeting.

Finally, we gratefully recognize Dorothy Costa and Katherine Kellum for their contributions throughout the process of planning, holding the meeting, and preparation of these Proceedings.

Planning Committee:

Joseph Saucier, Chairman, Southeastern Forest Experiment Station
Fred Allen, Georgia Forestry Commission
Paul Barnett, Tennessee Valley Authority
A. B. Curtis, Jr., National Forest, Region 8, State and Private Forestry
Peter Dress, University of Georgia, School of Forest Resources
Winfred Haynes, University of Georgia, School of Forest Resources
James McMinn, Southeastern Forest Experiment Station
Jim Neal, University of Georgia, Cooperative Extension Service

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Winfred N. Haynes, Moderator

WELCOME TO THE FOREST BIOMASS FOR ENERGY FORUM

by

Leon A. Hargreaves, Jr., Dean
School of Forest Resources
University of Georgia

The School of Forest Resources is pleased to present this forum in conjunction with and preceding the Sixth Annual Southern Forest Biomass Workshop. This meeting of researchers and practitioners from universities, government and industry provides an excellent backdrop for a review of programs and policies that guide the increasingly important energy aspects of forest resource management.

We have seen in the past decade a renewed interest in an old fuel--that of wood. This interest is viewed with both enthusiasm and reservation. Enthusiasts see a developing fuelwood market with prospects for utilizing portions of the forest resource which have been largely wasted, while others express concern for its impact on conventional forest products. Clearly, there are both opportunities and risks in promoting forest resources as an alternate energy source.

This forum is planned for industrial and government forest managers to participate with leaders in government and industry for the purpose of reviewing programs and policy issues guiding effective development of forest biomass for energy in the coming decades. I am certain you will have a stimulating and productive meeting.

THE UNIVERSITY ROLE IN BIOMASS RESEARCH[1]

Nathan W. Dean[2]

INTRODUCTION

There's a revolution under way, and it could change the economy of Georgia.

The revolution is called biotechnology. It uses new techniques developed in the last few years through basic research and molecular biology to make specific genetic changes in living cells. With these techniques, it will be possible in the near future to make significant improvements in the production of food, fiber, fuel and medicine.

In one sense, biotechnology has always been with us. Agriculture itself is basic biotechnology as are the fermentative processes which give us bread, wine and cheese. But with the advent of a new technique known as "genetic engineering," the applications of biotechnology can expand to dimensions mankind has never before known.

An emphasis on biotechnology could lay the foundation for Georgia's future economic growth. With its unique resources already in place, Georgia could lead the Nation into the 21st Century in the production, conversion, processing, marketing, and distribution of biological resources.

GENETIC ENGINEERING

Genetic engineering is, in theory, a vastly more efficient form of cross-breeding. In the traditional approach, the breeder selects plants or even species with desirable traits and crosses them, hoping that the offspring will inherit both desirable traits, but not at the expense of compounding the undesirable traits.

By means of genetic engineering, it has become possible to isolate the genetic components responsible for particular traits, "snip" them out of one species and introduce them into another.

The Effect is Already Apparent

Biotechnology and genetic engineering have made feasible a number of scenarios which could prove of enormous benefit to mankind.

*In agriculture, genetic engineering lends the potential of producing a herbicide-resistent corn crop, plants that could "protect" themselves from frost damage, or plants that could produce their own pesticide to ward off damaging insects.

*Bacteria have already been created which carry the human gene responsible for insulin production in the pancreas. Commercial production of insulin using these bacteria is now under way.

*Biotechnology can mean cheaper and more efficient fuel production. Already, industry is mass-producing ethanol as a cheaper substitute for fossil fuel. A genetically-engineered bacterium could speed up the ethanol-producing process and make this substitute fuel cheaper and more plentiful.

*For years, organic chemists have been aware that existing technology was quite insufficient in the development of chemical "starting ingredients" or "feedstocks," the first step in making many products such as plastics. With the newly-found cooperation of bacteria, the greatest long-term potential for biotechnology may be a highly efficient system of production of major industrial chemicals.

THE CHALLENGE

Through research, man can achieve a level of understanding of life processes that will permit the genetic alteration of plants, animals, and micro-organisms in safe and agronomically sound ways. Since we have reached the limits of the ability to increase output through conventional agricultural means, the future depends on the emerging ability to implement this new biotechnology.

Biotechnology is ethical, efficient, and profitable. It is already a $2.5 billion industry, and analysts have predicted that it will eventually impact as much as 70% of the gross national product. Biotechnology will be the economic giant of the 21st Century.

1/ Presented at the "Forest Biomass For Energy--A National Policy Forum," School of Forest Resources, University of Georgia, Athens, Georgia, June 5, 1984.

2/ Acting Vice President for Research, University of Georgia, Athens, Georgia.

The Imperative for Action

By the year 2000, the world's population will exceed 6.3 billion, a staggering 33% increase since 1975. These additional 2 billion people will require food, fiber, and fuel from a world economy which is presently based on fossil fuels. The pressures that will be exerted on these and other finite resources by a large world population will raise the specter of wide-spread famine and war.

Researchers at the University of Georgia know that a partial answer to this critical world challenge lies in the biological resources of Georgia and the Southeast. The application of biotechnology can contribute in two important ways.

A Decreased Dependence on Fossil Fuels

By making agriculture in the world's developed countries more efficient, we can decrease our dependence on petroleum-based energy. Developed nations can also benefit from alternative energy "farms" in the production both of energy for local needs as well as in the production of chemical feedstocks to replace petroleum products.

Exporting Biotechnology Expertise

Biotechnology applications (including improved breeding stock and fermentation processes) can be exported to Third World countries. Biotechnology fits the description of "appropriate technology" necessary to bring the standard of living for the majority of the world's present population up to subsistence level. Once the application of biotechnology has allowed such countries to amass sufficient capital, they can become consumers of the more sophisticated goods and services that biotechnology will produce in developed nations.

GEORGIA'S POTENTIAL

In developing biotechnology research and industry, Georgia has three enormous assets:

A Climate and Geography Well-suited to Agriculture

Georgia is the largest state in land area east of the Mississippi. Two-thirds of its 59,000 square miles lie in the fertile coastal plain region. Georgia has more different soil types than all but two other states, and has the largest underground water supply in the Nation. In addition, an ample annual rainfall and a mild climate allow a growing season of 230-250 days in the major crop-producing section of the State.

Substantial Agribusiness Already in Place

The State ranks first nationally in the production of pulpwood, paperboard and naval stores and second in the growth of timber with 25 million acres of forest land. Georgia is 17th in the Nation in food production with more than $3 billion in cash receipts yearly. The State also has two deep-water ports and solid connections, both national and international, in transportation, trade and banking.

The Talent and Expertise at the University of Georgia

Over 500 investigators are working at the forefront of research in the areas of botany, genetics, veterinary medicine, microbiology, agronomy, biochemistry, ecology, soil science, and dairy science, to name but a few. The annual research budget of the University exceeds $75 million, about half from external sources, and has been increasing despite economically difficult times and recent cut-backs in federal research support. This continued growth is indicative of the quality of work, particularly in the life sciences, which makes the University of Georgia a world-class research university.

The work that the University of Georgia scientists are doing can meet the challenge posed by declining petroleum-based energy resources and the expanding world population. Several examples of this work illustrate the potential benefits which lie ahead.

Plant Sciences

In plant biology research, University of Georgia scientists are exploring the regulation of plant gene expression, plant metabolism, photosynthesis, hormonal control of development, cell structure, applied plant genetics, and control of plant pathogens.

Animal Sciences

Research in animal science includes work on the hormonal regulation of gene expression in development, vaccine development, chemotherapeutic agents, physiology and microbiology, and aquaculture.

Microbiology

Fermentation research makes use of improved strains of micro-organisms to recover energy from plant material. Other microbes are being studied for their ability to enhance recovery of crude oil and precious metals.

Ecology

Athens ecologists have devised a method based on modern biology and paleobiology to predict optimum sites for petroleum exploration in the North Sea. Other work concerns the structure

of soils with respect to their ability to absorb and release organics such as fertilizers or pollutants.

THE FUTURE

The greatest asset that the University of Georgia has to offer is that it is a university. Through its threefold mission of teaching, research, and service, it trains the problem-solvers of the future, creates the tools they will use, and prepares the public to deal with the coming century.

To focus its unique capabilities on the problems just described, the University has created a new program in Biological Resources and Biotechnology. This initiative will bring together the fundamental research abilities of UGA's basic life scientists and the applied science efforts of its faculty in agriculture, pharmacy, and veterinary medicine. From their collaborative efforts will come the new knowledge needed to transform these possibilities into reality.

USDA FOREST SERVICE POLICY AND PROGRAMS ON FOREST BIOMASS FOR ENERGY[1/]

F. Bryan Clark[2/]

In this presentation I will address the national energy policies in the United States, followed by the policies of the U.S. Department of Agriculture and the Forest Service, particularly as they relate to Georgia and the Southeastern United States. Georgia is an especially appropriate place for concerted biomass efforts because its size and range of physiographic conditions lead to high biomass productivity and it is typical of Southeastern states.

First, a little about the nature of national policies. Policy is seldom hard and fast or absolute. Good policy needs a degree of looseness to fit the many diverse situations found throughout the United States. Policies are also constantly shifting and evolving over time in response to many things--public pressure, changes in economic conditions, new information, as well as shifting political philosophy about the appropriate role of the Federal Government.

The National Energy Policy is a classic example of this process at work and has a bearing on my topic of Forest Service programs on forest biomass for energy. We all remember the two energy crises in the 1970's when the oil supply was arbitrarily reduced by the OPEC countries, creating all kinds of problems like the frustration of spending hours in gasoline lines. Americans felt that they were victims of circumstances over which they, or the market place, had little control. This set into motion a public demand to do something. The Federal Government responded. Congress passed the Energy Security Act in 1980, aimed at making the United States more energy self-sufficient. The importance of biomass energy was recognized in Title II of that Act. You are all aware, in fact involved, in the many energy initiatives that grew out of this major policy change--more research, financial incentives for energy production, energy demonstration projects, and an energy conservation program.

1/ Presented at the "Forest Biomass For Energy--A National Policy Forum," School of Forest Resources, University of Georgia, Athens, Georgia, June 5, 1984.

2/ Associate Deputy Chief for Research, USDA Forest Service, Washington, DC.

The primary role of the Federal Government with respect to energy is to establish and maintain sound policies based on economic principles that promote energy production and use. This strategy recognizes that most of the decisions about using and producing energy in this Country are made by millions of individuals--consumers, managers, inventors, and investors--throughout the Country in the private sector. This emphasizes the importance of allowing our market economy to function to ensure that these decisions are as productive and efficient as possible. I think it is important that we understand that the most promising way to meet our energy needs is to let the free market forces work and focus Federal Government energy programs on limited but important responsibilities such as support of longer term, high-risk research and development.

Now let use trace the development of energy initiatives in the Department of Agriculture. As early as 1976, the U.S. Department of Agriculture formalized a broad set of goals to help solve the energy problems of the Nation. The initial four goals were:

1. Assure energy supplies for essential food, fiber and forest production.
2. Provide maximum support to short and long-term energy conservation.
3. Develop the energy potentials of biological materials and wastes.
4. Facilitate the environmentally sound development of energy reserves of coal and other resources on Federal lands.

Three years later--in 1979--the Secretary of Agriculture set a fifth USDA goal that is straightforward and ambitious:

5. Support activities to assure that agriculture and forestry become energy-self-sufficient by 1990.

The energy objectives of the Forest Service are contained in two basic documents:

1. Forest Service Manual, Chapter 2170, Energy Management.

2. "A National Energy Program for Forestry," which is USDA Forest Service Miscellaneous Publication 1394, published in October 1980.

The Forest Service Manual documents legislative authority for action in functional areas, and fixes responsibility for specific action at designated administrative levels. Excerpts from the Manual on Energy Management apply directly to the policy and program questions addressed by this forum and workshop. These include the following policy statements:

° Provide leadership and support for environmentally acceptable and scientifically sound development, production, and use of all energy resources from forest lands.

° Favor energy use from renewable resources.

° Provide national leadership in the production of forest biomass for energy.

It is the responsibility of the Chief to establish management goals and provide overall direction for Forest Service energy programs and to provide Forest Service inputs into the energy-related programs of the USDA.

The Deputy Chiefs for the National Forest System, Research, and the State and Private Forestry have the following responsibilities:

° Facilitate environmentally acceptable development of alternative energy resources on National Forests.

° Plan, develop, and implement programs in cooperation with state foresters to facilitate production and use of renewable forest and urban biomass for energy.

° Identify energy research needs.

° Coordinate overall Forest Service biomass energy activities and serve as primary contact with the Department of Agriculture Office of Energy, Department of Energy, and other agencies concerned with energy production and conservation and related environmental issues.

° Conduct research on silviculture, harvesting, transportation, conversion, utilization, and environmental impact as related to forest biomass for energy.

At the field level, regional foresters have responsibility to demonstrate and implement new methods to grow and harvest forest biomass and for other energy resource management programs. The Experiment Station Directors have responsibility to provide technical knowledge for biomass energy production and use to help meet Forest Service objectives. In meeting these responsibilities we have cooperated with a number of universities and other governmental agencies including the Department of Energy represented by Dr. Beverley Berger in this Forum.

Having assigned various divisions of responsibility, the Forest Service proposed in 1980 a coordinated program in support of the Department's 1990 goals for energy self-sufficiency in agriculture and forestry. The overall 1990 program objectives are:

1. An annual production of 6.4 quads of energy from forest biomass.
2. Annual conservation of 2.0 quads of energy through improved efficiency in the production and use of wood products.
3. Development and implementation of environmental protection guidelines in connection with production and use of wood for energy.

To meet the production objective, we have the following five major areas of emphasis:

1. Develop Current and Accurate Resource Information.
2. Improve Forest Management.
3. Recovery of Forest Biomass.
4. Substitute Petrochemicals and Fuels with Biomass-derived Counterparts.
5. Stimulate Increased Use of Wood Fuel.

We have specific research projects in each of these major emphasis areas.

<u>Develop Current and Accurate Resource Information</u>

At several Experiment Stations, including here in the Southeast, we have projects that are developing techniques to measure and classify the total biomass resource. These data are then incorporated into traditional inventory procedures that allow state, regional and national biomass estimates and also identify the best potential use for the resource. Other related activities include the development of regional or site-specific wood supply and demand models. I might add that the Southeastern Station leads the way in the Forest Service in this emphasis area. The total tree and tree component weight and volume equations developed by the Research Unit here in Athens, have been incorporated by our Resource Inventory Group so that state biomass resource inventories in this region are now a routine procedure.

Improved Forest Management

Again, at all Experiment Stations we have large research commitments to the development of silvicultural and management techniques for maximizing biomass production in natural stands in plantations. At the Southeastern Station we have research in soil and water relationships, genetics, tree improvement, stand establishment, and stand management, for both pines and hardwoods. Research in short-rotation culture of fast-growing species such as aspen, hybrid poplar, sycamore, eucalyptus, and red alder is well under way at various locations. As you know, some of the earliest intensive-culture research was done cooperatively by the Forest Service and the University of Georgia in what became known worldwide as the silage sycamore concept.

The Forest Service, in cooperation with states and other organizations, has stepped up its programs of technical assistance to nonindustrial forest landowners. Recently, the Forest Service, in cooperation with the Georgia Forestry Commission, initiated a 3-year pilot project to demonstrate that regeneration of harvested forestlands can be financially attractive. Removal of unmerchantable trees and logging residue not only increases wood supply and increases income to the landowner, but also, traditional site preparation costs are reduced or eliminated.

Recovery of Forest Biomass

Increasing productivity of our forests is of little value unless the wood is harvested, processed and delivered to the user at a reasonable or competitive price. Conventional harvesting equipment is designed for large and relatively uniform logs and trees. This equipment is generally too large and uneconomical to use to harvest forest residues. Recognizing the need for research and development of new equipment and for modifying and testing existing equipment that is specifically suited to biomass harvesting, the Forest Service initiated several projects in this area.

Equipment that has been developed includes the Nicholson-Koch mobile swath harvester developed at the Southern Station, the topwood harvester and chunk-wood harvester developed at our Houghton, Michigan Laboratory, and several cable-yarding systems developed at our Missoula, Montana Equipment Center that are suitable for harvesting small timber. Other locations, such as our Engineering Unit at Auburn University, are principally concerned with production and cost of different harvesting systems.

Substitution of Petrochemicals and Fuels with Biomass Derived Counterparts

Research in this area is largely concentrated at our Forest Products Laboratory in Madison, Wisconsin. The Forest Service has a long history of research on wood hydrolysis, but in 1980 a new program was started. This program was based on a new two-stage process concept which has a prehydrolysis step prior to the main hydrolysis stage. That program has now progressed to the pilot plant stage. The pilot plant will be designed and constructed by TVA in cooperation with the Forest Products Laboratory and will incorporate the newly developed technology.

Other promising research at the Forest Products Laboratory concerning liquid fuels is an area that we refer to as Biotechnology. In this program, scientists are conducting fundamental research in microbiology, enzymology, and lignin chemistry as it relates to fermentation processes and other biological reactions. This is high-risk research, but it provides our only hope for a major breakthrough in this emphasis area.

Also in this area of petrochemical substitution, we have scientists in the Forest Service and others at several universities, including Dr. Chen here at the University of Georgia, whom we are supporting, that are conducting basic research in quest for a natural adhesive from wood and bark. Adhesives derived from petrochemicals are a large and expensive component of our forest products industry. Natural adhesives have the potential of reducing manufacturing costs and environmental risks and for creating a high-value market for residues such as lignin and bark.

A major breakthrough in this same emphasis area was made a few years ago by Forest Service scientists here at the Southeastern Station when they discovered a method for greatly increasing the production of oleoresin from southern pines. They found that application of small quantities of the herbicide Paraquat on the stem of living trees caused large deposition of oleoresin in the wood behind and above and below the point of application. This discovery led to an entirely new technology for the production of Naval Stores.

Stimulating Increased Use of Wood Fuel

Use of wood for home heating and for industrial process energy has a number of barriers that limit its development. Heating of modern homes with wood will require design accommodations for such factors as circulatory heating, homes being unoccupied for several hours daily, higher wood prices, stringent building codes, air-quality standards, and potentially higher insurance rates. Industrial use of wood for fuel depends on other factors such as the requirement for large sustainable supplies, different costing procedures, environmental regulations, facilities for storing, handling, and burning of a bulky, heterogeneous fuel mix.

Program needs to overcome these barriers are listed in the following action items.

- Identify specific market opportunities for unused wood and develop strategies to implement its use.

- Develop reliable merchandising schemes to supply the growing demand for residential fuelwood.

- Develop efficient and convenient residential heat plants.

- Develop reliable wood gasifiers.

- Develop improved handling and processing procedures for biomass feedstocks.

- Develop guidelines for the safe installation and use of home wood-burning appliances.

The Forest Service has only limited involvement in the design and development of wood combustion systems. Private sector equipment manufacturers have made great progress in this area. We are involved--and support a number of state and local governments with their energy programs. These include providing resource assessments and identification of unused wood sources suitable for fuel, assistance with demonstrations of harvesting, and processing of biomass feed stock; and we have implemented controlled firewood cutting on National Forests. We have also developed and published guidelines for safe installation and use of home-heating appliances.

In spite of the indicated barriers to use of wood for fuel, wood for energy has made significant increases in the last 10 years. A study conducted by the Forest Service, in cooperation with the Wisconsin Survey Research Laboratory, found that during the 1980-81 heating season 22.2 million households or 28 percent of U.S. households burned 42 million cords of wood in primary and secondary homes. The market, while defuse, is large. By comparison, the 42 million cords is approximately one-third the pulpwood volume utilized by the U.S. pulp and paper industry in the same period.

Regional consumption of wood for fuel is surprisingly uniform throughout the Country. While the average amount burned per household is higher in the Northeast and North Central regions, a larger percent of households burn wood in the West and South. The larger participation in the South and West reflects the greater availability of wood to rural dwellers. The fuelwood burned during the 1980-81 heating season contained about 0.8 quads of energy. This is about 9 percent of the total energy used by U.S. households. All indications based on stove sales, chain-saw sales and firewood permits issued suggest that this market is growing at a pace of about 10 percent per year.

Impressive as the growth of residential fuelwood use has been, significantly larger total amounts of wood fuel are used in industry, and growth in this sector is also steady.

In the period from 1974 through 1983, the pulp and paper industry has increased their level of energy self-sufficiency from 38 percent to 55 percent from self-generated and residue sources. These figures are even more impressive considering that their production output was increased 25 percent during the same period. The solid wood products industry is by far the largest user of wood for fuel. This sector has now achieved 70 percent energy self-sufficiency by burning self-generated residues such as bark, sawdust, and trim for boiler fuel.

Other fuelwood markets are growing. These include nonforest-based industries such as brick and textile manufacturers, some of which you have here in Georgia, and at state and federal institutional facilities, such as schools, hospitals, prisons, and at power-generating utilities.

In summarizing our progress from a production point of view, we have doubled our national energy production from wood in the last 10 years. We estimate that we are currently producing about 2.2 quads (quadrillion Btu's) of energy per year from wood which is about 2.9 percent of the total U.S. energy use. With good forest management and application of effective technology, we estimate that wood can provide from 7 to 10 percent of the Nation's energy.

The other major program areas mentioned earlier were Conservation and Environmental Protection. I will discuss these only briefly, not that they are any less important than the production program area but these topics are less germaine to this Forum.

The conservation of energy in all activities, from the establishment of forest stands to the use of forest products by the consumer, can save significant amounts of energy. We have identified options which, if adopted, could result in an annual savings of 2 quads by the year 1990.

Some of our research activities right here in Athens relate to this general topic. Our wood products unit is developing new structural composites from low-quality material. The University of Georgia, through a cooperative project with the Forest Service, developed an algorithm for the efficient transportation of residues for energy from supply points to potential demand points.

The Forest Service is committed to the policy that increased production of biomass for energy should not be made at the expense of environmental quality. We know that increased utilization offers positive forest management benefits. The reduction in logging residues will reduce slash-related fire hazards. However, research has not fully evaluated the results of increased biomass removal.

We need hard data on the impact on soil, water, nutrients, wildlife and other amenities. We also need to know more about such things as the potential pollution problems that can result from residential wood burning. Again, work based right here in Athens, addresses some of these questions. The University of Georgia through a cooperative agreement with the Forest Service is estimating potential nutrient drain from intensive whole-tree fuel chip harvesting.

So, you can see that the Forest Service is involved to make wood available for energy. We are open to creative ideas and innovative approaches. It takes creativity and imagination to work against adverse economic factors to utilize wood for energy. It is truly a cooperative effort between government (Federal and State) and the private sector. It is also a job that will not get done without extra effort from many people. The Forest Service will not let our national policies--now or in the future interfere with our goal of utilizing wood for energy when that is the <u>highest and best use of the resource</u>. We are concerned with overall good resource management, and using wood for energy has an important role to play in good forest management. Research programs such as those here in Georgia are responsible for making wood for energy work. I know this workshop and in particular its participants will continue to use creativity to get the job done. The extra effort and creativity are, in my opinion, the key to your success--both in the past and in the future.

THE FOREST INDUSTRY AND WOOD ENERGY IN THE

CONTEXT OF U.S. ENERGY POLICY[1/]

Aleberto Goetzl[2/]

INTRODUCTION

The preceeding speaker focused on U.S. Forest Service activities relating to biomass — wood — energy in the United States. Biomass itself is an interesting term. It refers to "the amount of living matter (as in a unit area of volume of habitat)." It is a term which is most often used in the forestry and energy communities to encompass agriculture and forest resources suitable for energy uses. It is <u>not</u> a term that foresters traditionally have liked to use. Can you imagine a tree falling in the forest and the logger yelling to his comrads in warning: "Biomasssss..."

As the second speaker in this forum, I believe my role is to place in perspective the Nation's use of wood as a fuel with particular attention to what is going on in the forest industry. I will talk about the current consumption of wood in the forest products and paper industries, some of the policy questions which do not directly bear on the use of wood but, nevertheless, have important implications for alternative energy sources, and finally, what I perceive to be occurring in wood markets generally and wood energy specifically.

BACKGROUND

Let me recap a few numbers which have already been mentioned or which, I am sure, you have read elsewhere.

Americans consume about 44 million cords of wood in their homes. This represents about 35% of all the wood energy consumption. An extremely small amount, perhaps 1-2%, is consumed by the nonforest-related industrial and commercial sector. The bulk, 60-65%, is consumed by the forest industry. This amounts to somewhere on the order of 1.5 quadrillion Btu's. I say somewhere because, as you know, the statistics on wood energy are soft, extremely hard to pin down. Wood energy markets -- in contrast to those of conventional fuels — are largely unregulated and therefore difficult to quantify. But let me describe the forest industry energy use in other terms.

In 1983, the wood products industry and the pulp and paper industry used the equivalent of 247 million barrels of oil in wood-derived fuels. Total net U.S. oil imports in 1983 were 4.2 million barrels/day. Therefore, the industry used the equivalent in wood fuels of a 59-day supply of oil. So, you can see the forest products industry is a leader in wood energy use — and you might also say, a leader in energy conservation through alternative fuels.

In the wood products industry in 1983, we estimate that 400,000 billion Btu's (.4 quads) of wood-derived energy was consumed. This takes the form of bark, sawdust, shavings, edges and ends, and so-called "dirty" chips. Actual data is only available for a handful of producers, but a survey of the industry conducted in 1981 revealed that the experience of these companies is generally representative of the industry as a whole. These companies relied on wood fuels for 75.8 percent of their total energy requirement (Table 1). Interestingly, the most dramatic trend in our statistics is in the purchased wood fuel category. The amount of wood energy in this category has grown 192% since 1978. This is "hogged" fuel that is now sold or marketed for energy by many wood products plants not large enough to have their own wood-using energy facilities.

On the paper side, some 1.15 quadrillion Btu's of spent pulping liquors, bark and hogged fuel was consumed in 1983 — 53.4 percent. This, by the way, represents an increase of 37% since 1972 and has permitted a comparable percentage reduction in purchased energy per unit of output over that 12-year period. There are now individual plants in the forest industry which are almost entirely energy self-sufficient and some which are net producers of energy.

The forest products industry is in a unique situation. Not only is a tree its principal raw material source, but it is also its largest source of energy. An additional feature of this industry is that it is the Nation's leading producer of cogenerated power. Wood-based fuels have much to do with this matter and I will go into more detail a little later.

[1/] Presented at the "Forest Biomass For Energy—A National Policy Forum," School of Forest Resources, University of Georgia, Athens, Georgia, June 5, 1984.

[2/] Executive Assistant, National Forest Products Association, Washington, DC.

Table 1.--Energy Use in the Forest Industries, 1983

Energy source	Units	Lumber and wood products[1] (15 companies)			Pulp and Paper[2]		
		Actual use	Billion Btu	% of total	Actual use	Billion Btu	% of total
Purchased electricity	MM KWh	5,244.6	17,894.5	11.0	40,530.1	137,934.3	6.4
Purchased stem	MM lbs	2,284.3	2,730.9	1.7	15,184.1	16,982.0	0.8
Natural gas	MM cf	10,072.7	10,258.0	6.3	309,309.6	314,877.5	14.6
Distillate fuel oil	M Bbl	386.9	1,909.0	1.2	1,002.1	5,991.0	0.3
Residual fuel oil	M Bbl	224.5	1,811.3	1.1	32,466.0	204,442.6	9.4
Coal	M Tons	106.8	2,751.7	1.7	12,132.3	299,803.0	13.9
Other conventional energy		-	1,930.0	0.3	-	3,060.6	0.1
Energy sold (API)		-	-	-	-	(21,568.0)	-
Total electricity, steam and fossil fuels		-	39,285.4	24.2	-	963,838.6	45.6
Self-generated hogged fuel, wood & bark	M Tons	12,277.6	111,828.5	68.7	39,988.2	330,351.7	15.3
Purchased hogged fuel, wood & bark	M Tons	1,239.9	11,308.2	7.0	-	-	-
Spent pulping liquors	M Tons	-	-	-	68,849.0	824,179.3	38.1
Other self-generated		-	224.7	0.1	-	21,305.4	1.0
Total hogged fuel, wood & other fuels		-	123,361.4	75.8	-	1,175,836.4	54.4
Total all energy		-	162,646.8	100.0	-	2,139,675.0	100.0

[1]Data for 15 large companies in the lumber and wood products industry accounting for 30% of U.S. lumber production and 70% of U.S. softwood plywood production.

[2]Data from the American Paper Institute Covering all producers.

I would like to draw your attention to some issues which perhaps you have not placed in the same context as wood energy, but these issues have implications for the expanded use of wood as an energy source.

America's attention to energy became all pervading immediately following the 1973 Arab oil embargo, and was refocused again in 1978 at the time of the Shah's demise in Iran. These two events demonstrated dramatically this Country's voracious appetite for energy and its vulnerability to external influences on energy supply. Such sudden shocks to the energy economy warranted political action and Congress found itself devising ways to mitigate any further sudden increases in energy prices or threats to the national security. 1978 was the banner year in terms of new energy legislation, which included: FUA (the Fuel Use Act), PURPA (the Public Utility Regulatory Policies Act), NECPA (National Energy Conservation Policy Act), NGPA (National Gas Policy Act), and ETA (the Energy Tax Act). Two years later the catchall for everything that was left out of these initiatives was enacted in the Energy Security Act of 1980.

The various legislative initiatives have made for an extremely complex energy regulatory environment. Most have come a long way in meeting their original objectives. Others have been less successful or bogged down in regulatory or judicial proceedings. But, many of these legislative and regulatory initiatives have had an impact on wood energy development and use. A few examples I will highlight are: cogeneration opportunities resulting from PURPA, Energy Investment Tax Credits, Energy Taxes generally, environmental regulations, and funding for energy research.

Cogeneration

Cogeneration refers to the simultaneous production of electricity and heat, itself used for energy. The latter is transformed, usually into process steam to operate plant machinery. Cogeneration is an extremely efficient use of energy resources. As an example, a typical public utility converts around 27%-39% of its Btu input into electric power. In contrast, a forest industry plant can convert over 80% of its Btu input into both electricity and process steam.

In 1978, PURPA required that utilities purchase electricity generated by small power producers to encourage cogeneration and energy efficiency. According to PURPA regulation, "full avoided" cost is paid to the cogenerator or small power producer, which means that the utility pays what it would cost to generate that power from other sources. As a result of this incentive, cogeneration has increased in the forest products industry. Unfortunately, provisions of PURPA which apply to cogeneration and small power production have been subject to numerous legal proceedings and congressional debate. With 3500 megawatts now in place in this industry, the American Paper Institute estimates that up to 40% more cogeneration is possible within the next 5 years.

But it is not only PURPA, acting alone, which promoted this energy pattern. It is PURPA coupled with the relative advantages of wood fuels in the forest products industry that makes this such an attractive investment opportunity for many plants. With cogeneration, the wood industry can get more than 80% efficiency. Power is provided to an area grid tempering the need for expensive new fossil-fuel or nuclear energy plants.

Cogeneration has also made attractive a number of investments in nonforest industry facilities. Certain schools, government agencies and other industries have embarked on cogeneration projects using wood fuels — supplied primarily from sawmill residues.

Energy Investment Tax Credit

An interesting thing happened on the way to energy taxes recently. The Senate Finance Committee chaired by Robert Dole, put together a package of tax increases — revenue enhancers — and spending reductions designed to shave $142 billion off the federal budget deficit over the next 3 years. During the deliberations over this package, an amendment was attached to include certain provisions of S 1619, a bill introduced last year and not given much attention. The Committee understood it was an energy-investment tax credit bill, but looked at the numbers and decided to go along.

What no one realized immediately was the bill extends investment energy tax credits for biomass for all industries except two: pulp and paper industry and the wood products, which are specifically excluded. These two industries do more to reduce dependence on imported oil than any other group, and yet they are being singled out because they have committed themselves to greater wood energy use — with or without the tax credit. This is no small matter. The industry's position is that biomass energy tax credits, if available at all, must be made available to all users. If not, wood is specifically being subsidized as a fuel in only some industries, distorting wood markets generally and diluting the purpose of the credits to begin with -- to encourage greater use of wood energy.

Energy Taxes

With crises brewing once again in the Persian Gulf and enormous federal deficits awaiting response, the scene is set for Congress to consider energy taxes. There have been several proposals, which have included an excise tax on fuel oil, a Btu tax, and an oil import fee. All have their drawbacks to particular regions, industries or other interest groups. Suffice it to say that a broadly applied Btu tax would contradict efforts at reducing fossil fuel and imported oil consumption. Many boilers have been converted from more efficient fossil fuels to wood. While the result has been a lessened reliance on oil and a reduction in the purchased Btu energy use per unit output, there has been an increase in total Btu use per unit of production. Hence, a Btu tax would impact further conversions to wood. This points to the need to carefully consider and analyze all of the implications of energy policy. Often, if not thought out, laws and regulations designed to some problems fall short of noble intentions.

Environmental Aspects

There are several environmental issues that pertain to wood energy. Obviously, discharges from residential stoves is one. Another concerns standards for industrial boilers. The EPA is being sued by environmental groups to expedite issuance of New Source Performance Standards for small industrial boilers. Most of the new wood-fired boilers in the wood products industry are small -- less than 250 million Btu/hour -- and hence would be subjected to the regulation. Seventy-five to 100 percent of all boilers sold to the lumber and wood products industry would fit into this size category. Among the pollutants to be regulated are sulfur dioxide, nitrous oxides, and particulates. Wood is low in sulfur and nitrous oxides and particulates can be expensive to control in small boilers. Wood may be lumped with coal and other solid fuels in these standards. A separate standard, which considers advantages of boilers as compared with other fuels would serve to encourage wood use for energy. Here, a separate standard may tip the scales in favor of a wood boiler in a decision between wood and coal.

The issue of acid rain is also potentially a serious one environmentally and impacts greatly the forest industries. The industry is affected if timber resources are damaged and it is affected if regulations are imposed on energy facilities. There are costs on both sides. This is a challenging issue for the industry, which requires careful forethought and knowledge.

Energy Research

A large amount of federal money is appropriated for energy research. Notwithstanding the deficit, the forest industry is generally supportive of research which addresses high risk, long-term problems. We support Forest Service inventory efforts and some of the DOE-funded research on perplexing energy technology problems. However, we quite frankly are less impressed as an industry with development and promotion programs designed to stimulate wood energy usage with the use of subsidies or selective low interest loans. Wood is good, but incentives for wood energy at the exclusion of product uses are, in my view, counterproductive.

Finally, let me look at one possible future scenario with respect to wood energy. The projections which have been made in recent years are confounding and, in my view, wholly erroneous. They range from a doubling to a ten-fold increase. Even though wood comprised 98 percent of all U.S. energy consumption in the seventeen and eighteen hundreds, actual use has never exceeded much more than 2 - 2.5 quads (Figure 1). Wood energy will certainly increase in use during the next 20 years. But, it is unlikely that the demand for wood energy will more than double even under my most optimistic scenario. This, of course, is hedged on the assumption that demand for wood products remains strong and that energy prices generally do not increase at sudden and alarming rates as they have in the past. This latter factor is perhaps what separates my view from others.

The trend line which began in 1973 has tapered off. We have been and are being successful in improving the choices to the consumer for energy products, and conservation has played a very significant role. The primary place to increase wood energy use is in the forest

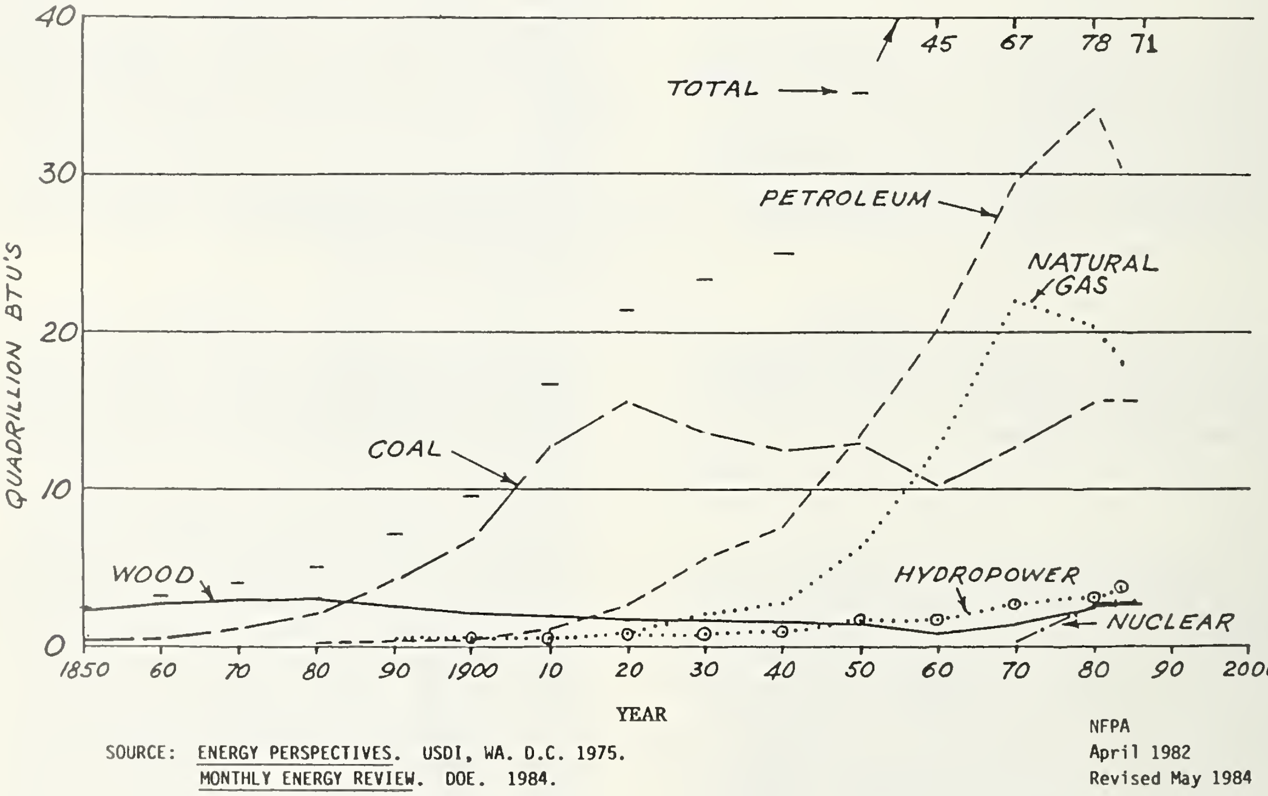

Figure 1.--U.S. Energy consumption trends--1850 to 1984.

industry, which has ready access to supply, can allocate wood resources efficiently relative to current markets, and has opportunities for cogeneration, making wood energy a very attractive energy alternative. My guess is that wood use in the residential sector has peaked, that most increases will occur in the forest industry and in other industries located in rural areas where wood supply — especially residue -- is economically procured.

In conclusions, let me leave you with these thoughts:

1. Biomass energy improves the investment in forest management by providing markets for previously unsaleable thinnings and residues. This is true for nonindustrial landowners as well as industrial landowners where residue extraction is being integrated with harvesting and site-preparation practice.

2. The forest industry is the leader in biomass energy. Future increases in its use will occur predominantly in this sector.

3. Increases will occur in the near term because of opportunities associated with cogeneration.

4. Biomass subsidies are unnecessary and detrimental if not applied uniformly.

5. The focus should be on producing forest products, improving the quality and quantity of wood, and the use of residues for energy will follow.

We should not relax efforts toward energy security by forgetting the serious lessons of the 1970's. The events in the Persian Gulf of the past few days keep us sensitized. But, there is a bright side; we have made progress. Imports from the Persian Gulf are now running about 770,000 barrels per day, 2,000,000 barrels less per day than several years ago, with no major impact on supply and prices. We have a way to go to reduce dependency further, keep energy in a range of affordability, and conserve resources.

Let's look to increasing energy efficiency. Let's invest in domestically available and renewable energy resources such as wood. Let's do it sensibly. Let's understand where the greatest opportunities are and devote our "energies" accordingly.

WELCOME TO THE SOUTHERN FOREST BIOMASS WORKSHOP

by

Dr. Eldon W. Ross
Director
Southeastern Forest Experiment Station
USDA Forest Service
Asheville, NC

On behalf of the Forest Service, Southeastern Forest Experiment Station, I welcome you to the Sixth Annual Southern Forest Biomass Workshop and here to the campus of the University of Georgia. As you probably know, the Southeastern Station has one of its largest laboratory facilities here on campus. It's just a couple of blocks from here. If you haven't already done so, I hope you will find the time to visit our laboratory.

It is really good to see so many gathered here to talk about forest biomass. It wasn't so many years ago when such a meeting couldn't have been held for lack of attendance. Some scientists--particularly ecologists--were interested in biomass, but few others were. Interest in wood as a fuel changed all that. Now, forest managers and many consumers and potential consumers want to know about forest biomass production.

It is that desire, more than anything else, that has permitted the Southeastern Station to put together a major biomass research effort led by Joe Saucier. The biomass research we are doing at the Southeastern Station is really a model of cooperative effort. I know many of you here are partners in that effort. Cooperators include 20 pulp and paper companies, 4 State forestry organizations, 2 Federal agencies in addition to the Forest Service, and, of course, universities. This Southern Forest Biomass Working Group is the catalyst that makes all this cooperation possible.

Although it was the energy crisis of the 1970's that stimulated interest in forest biomass, there are other good reasons for being able to measure and evaluate it:

1. Weight-scaling is widely accepted and highly efficient.

2. Tree-length logging is becoming an accepted practice.

3. Whole-tree chipping is becoming increasingly practical, particularly in stands that are not very attractive for conventional logging.

We used to ignore all the stems smaller than 5 inches in diameter in a timber cruise. But now, all of that has changed. Now those stems have value, which is best expressed in terms of their weight.

The big personal investments you have made in biomass research are paying dividends. You have produced equations and tables for predicting weights of trees and tree parts of many sizes and species. Our Forest Inventory and Analysis Work Unit is using the latest equations to prepare State and regional biomass estimates.

A large share of your effort has centered on this problem of estimation, and you've come a long way toward solving it. As we look ahead, there is still a big research job on influencing biomass production and on efficient use of forest biomass.

Meeting as you are this week will ensure continued progress through coordinated effort. I wish you well in your personal research and its application.

SESSION I

FOREST BIOMASS SAMPLING AND INVENTORY

Phillip H. Dunham, Moderator

DO DIFFERENT YOUNG PLANTATION-GROWN SPECIES REQUIRE DIFFERENT BIOMASS MODELS?[1/]

Bryce E. Schlaegel and Harvey E. Kennedy, Jr.[2/]

Abstract.--Sweetgum and water oak trees sampled from a plantation over 7 years were used to test whether primary tree component (bole wood, bole bark, limb wood, limb bark, and leaves) predictions could be summed to estimate total bole, total limb, and total tree values. Estimations by summing primary component predictions were not significantly different from predictions for the totals, but prediction variances were increased for sweetgum and reduced for water oak.

INTRODUCTION

When developing equations to predict tree biomass, the question of which independent variables to include in the prediction equation frequently arises. The allometric model $Ln(Y) = b_0 + b_1 Ln(D^2H)$ has proven to be a simple but accurate estimator for predicting bole volumes and weights for many tree species across a broad range of size classes. This model is useful since it uses an index of bole volume (D^2H) as a predictor of bole volume. Since bole volume and weight are highly correlated, D^2H is also a good predictor of bole weight.

If dbh (D) and either total height (H) or merchantable height (MH) are the only variables available for predicting tree volume or weight, then the choice of predictors to include in the model is limited to these two variables and their transformations. For trees grown in natural stands or in plantations of a single spacing, these variables are adequate for predicting tree boles; R^2 of 0.97 to 0.99 are common and associated standard errors are relatively small. But predictions of tree crowns using these variables alone are usually much less precise. This has caused little problem since the bole is usually the primary variable of interest and usually comprises the primary portion of the tree. In young natural stands or in plantations, competition strongly influences the proportion of crown and bole form, thereby making tree age an important tree volume or weight predictor.

It is a common practice for researchers developing biomass equations to use the same model form to predict primary tree components. Thus bole wood, bole bark, limb wood, limb bark, leaves, and the component totals are predicted using the same model form, such as the allometric model. One reason for this is to be sure all the prediction components can be added if linear models are used to predict an untransformed dependent variable (Kozak 1970). Also, a major effort is required to develop separate models to predict each component, with no assurance the additional effort will result in increased prediction reliability.

Additional questions of model form arise when several species with quite different growth characteristics occur in a plantation and tree component predictions are needed for each species. Are separate model forms required to accurately predict each component? If separate models are used, can the component predictions be added to give reliable estimates? Are separate model forms required for each species? The purpose of this paper is to answer these three questions using hardwood plantation data for testing.

THE DATA

The data are from a 7-year-old hardwood plantation growing in a minor stream bottom in southeastern Arkansas, approximately 10 miles

[1/] Paper presented at Sixth Annual Southern Forest Biomass Workshop, Athens, Georgia, June 5-7, 1984.

[2/] Bryce E. Schlaegel is Principal Mensurationist and Harvey E. Kennedy, Jr., is Principal Silviculturist at the Southern Hardwoods Laboratory, maintained at Stoneville, Mississippi, by the Southern Forest Experiment Station, Forest Service--USDA, in cooperation with the Mississippi Agricultural and Forestry Experiment Station and the Southern Hardwood Forest Research Group.

south of Monticello. Eight tree species were each planted in a randomized complete block design of four blocks and five spacings. The species were: sycamore (*Platanus occidentalis* L.), sweetgum (*Liquidambar styraciflua* L.), cottonwood (*Populus deltoides* Bartr. ex Marsh.), green ash (*Fraxinus pennsylvanica* Marsh.), water oak (*Quercus nigra* L.), cherrybark oak (*Q. falcata* var. *pagodifolia* Ell.), Nuttall oak (*Q. nuttallii* Palmer), and swamp chestnut oak (*Q. michauxii* Nutt.)

The spacings in feet and respective number of trees per acre (in parentheses) were 2 by 8 (2723), 3 by 8 (1815), 4 by 8 (1361), 8 by 8 (681), and 12 by 12 (303). Spacings were chosen to span from the narrow coppice spacings to the more usual pulpwood and saw log spacings. The 8-foot distance between rows was chosen to allow tending by standard farm equipment.

Each plot consists of 169 trees planted in a rectangular grid of 13 by 13 rows. The interior 5 by 5 rows were designated as permanent remeasurement rows with the outer 4 rows as a buffer.

Beginning in the fall of 1977, two trees representative of the plot from the second and third buffer rows were destructively sampled each fall for a total of seven annual samples. Field measurements included diameter 6 inches above the ground, dbh, total height, crown height, total bole weight, and total crown weight. Individual bole, limb, and leaf samples were taken and sealed in separate polyethylene bags for laboratory determination of green and dry weights and volume. One-inch thick disks were cut from the bole at a 6-inch stump and at intervals of 20, 40, 60, and 80 percent of total tree height. The branch and leaf samples consisted of selecting two representative limbs from each quarter of crown length and consolidating these into an eight-branch tree sample; leaves were detached from the branches in the field and bagged separately. Green weights, dry weights, and volumes of bole and branch components were determined in the laboratory by standard laboratory procedures.

Green weights of bole wood and bark for each tree were obtained by multiplying the proportion of each in the bole sample times the total bole green weight measured in the field. Green weights of branch wood, branch bark, and leaves were derived by adding the leaf and branch sample weights, finding the proportion of each component in the sample and applying the proportions to the total crown weight obtained in the field.

Total dry weights and volumes for each component were calculated using the consolidated sample component moisture contents and specific gravities. Moisture content and specific gravity were assumed to be uniform within each component.

Sweetgum and water oak were chosen to test the model development techniques. Sweetgum is very intolerant with rapid early growth. Young sweetgum have long conical crowns with the branches set at an acute angle to the stem. Water oak, though fairly intolerant, exhibits the slow early growth characteristics of the oaks. The stout, horizontal branches self-prune very slowly.

Only data for trees taller than 4.5 feet were included in the analysis set, giving 207 sweetgum and 175 water oak trees. These sets were reduced in size by one-third due to data set size limitations of the software package used for much of the subsequent analysis. Trees were randomly eliminated, leaving 131 sweetgum and 111 water oak. The following tabulation shows means and ranges of sample tree data.

	Sweetgum		Water oak	
	Mean	Range	Mean	Range
Age (yrs)	4.0	1 - 7	4.5	1 - 7
Dbh (in)	1.7	0.1 - 5.1	1.2	0.1 - 4.2
Total height (ft)	15.5	4.5 - 36.8	12.8	4.5 -23.0
Green bole wood weight (lb)	14.7	0.2 -117.3	8.4	0.2 -72.8
Green bole bark weight (lb)	2.3	0.05- 16.1	1.8	0.05-12.4
Green limb wood weight (lb)	4.8	0.07- 35.3	8.5	0.2 -86.2
Green limb bark weight (lb)	1.9	0.05- 14.8	1.8	0.08-15.6
Green leaf weight (lb)	5.1	0.1 - 34.0	3.8	0.3 -25.8

The tree component percentages for the two species differ due to their different growth characteristics (table 1). Based on dry total tree weight without leaves, both species contain about 85 percent wood and 15 percent bark in the tree, with another 15 percent in the leaves. Each species contains about 8 percent each in bole bark and limb bark. However, sweetgum has 64 percent of wood in the bole and 21 percent in the limbs, while water oak has 40 percent wood in the bole and 43 percent in the limbs. Thus water oak has half its weight in the bole and half in the limbs, while sweetgum is three-fourths bole weight and one-fourth limb weight.

ANALYSIS AND MODEL TESTING

In addition to tree diameter and height, other independent variables are needed when predicting biomass of plantation-grown trees. Tree diameter and height alone, when used as

Table 1.--Sample tree component mean and percent of 131 sweetgum and 111 water oak trees

Component	Sweetgum Mean	Sweetgum Percent of tree	Water oak Mean	Water oak Percent of tree
		Green weight - lb		
Bole wood	14.72	62	8.41	41
Bole bark	2.33	10	1.77	9
Total bole	17.05	72	10.18	50
Limb wood	4.84	20	8.51	42
Limb bark	1.86	8	1.77	8
Total limbs	6.70	28	10.28	50
Tree wood	19.56	82	16.92	83
Tree bark	4.19	18	3.54	17
Tree w/o leaves	23.75	100	20.46	100
Leaves	5.12	22	3.80	19
Tree w/leaves	28.87	122	24.26	119
		Dry weight - lb		
Bole wood	7.65	64	4.83	40
Bole bark	0.97	8	1.10	9
Total bole	8.62	72	5.93	49
Limb wood	2.54	21	5.30	43
Limb bark	0.81	7	0.94	8
Total limbs	3.35	28	6.24	51
Tree wood	10.19	85	10.13	83
Tree bark	1.78	15	2.04	17
Tree w/o leaves	11.97	100	12.17	100
Leaves	1.83	15	1.82	15
Tree w/leaves	13.80	115	13.99	115
		Volume - cubic feet		
Bole wood	0.233	57	0.123	38
Bole bark	0.049	12	0.031	10
Total bole	0.282	69	0.154	48
Limb wood	0.082	20	0.127	40
Limb bark	0.044	11	0.040	12
Total limbs	0.126	31	0.167	52
Tree wood	0.315	77	0.250	78
Tree bark	0.093	23	0.071	22
Tree w/o leaves	0.408	100	0.321	100

biomass predictors, were insufficient descriptors of plantation loblolly (Pinus taeda L.) crown biomass (Hepp and Brister 1982), plantation sycamore (Platanus occidentalis L.) (Willson et al. 1982), and natural loblolly bay (Gordonia lasianthus (L.) Ellis) (Gresham 1982). Earlier results showed that total tree height of plantation sycamore is a function of age, diameter, and initial planting density (Schlaegel 1981). Basic independent variables available for use in the present study are dbh--D, total height--H, tree age--A, and number of trees planted--N. Combinations, transformations, and interactions of these four variables were also used. The dependent variable used was the natural logarithm (Ln) of the component being fitted.

Since the purpose of this paper is to determine whether separate models are required for predicting each tree component for each species, it was assumed that separate models would give the most precise estimates for each component. All subsequent comparisons are against these individual component prediction equations.

Although only four basic independent variables are available, a large number become potentially available if transformations and combinations are considered. Based on scatter plots and past experience, 12 independent variables (table 2) were chosen for testing.

Table 2.--Twelve independent variables used to test the biomass predictors[1/]

Number	Variable	Number	Variable
1	D	7	$1/A^2$
2	H	8	D^2H
3	N	9	$Ln(D^2H)$
4	A	10	$[Ln(D^2H)]^2$
5	Ln(D)	11	[Ln(N)]/A
6	Ln(N)	12	N/A

[1/] D = dbh, H = total height, N = number planted per acre, A = age in years, Ln = natural logarithm.

The stepwise procedure of Minitab[3/] was used to fit equations to predict the 31 weights and volumes indicated in table 1. This procedure employs the technique of forward selection/backward elimination, which both adds variables to and eliminates variables from the equation, each variable's contribution to the reduction sum of squares being tested with $\alpha = 0.05$.

As might be expected, no single model form is consistently best for either sweetgum (table 3) or water oak (table 4). The number of variables entering the models ranges from two to eight but is usually four to six for sweetgum and three to five for water oak. With a few exceptions some form of the four basic variables will occur in all prediction equations for both species.

Relative equation precision is evaluated based on fit index, mean residuals, standard error, and coefficient of variation (Schlaegel 1982). These four statistics are calculated by converting the predictions into the units of pounds and cubic feet from their logarithmic form; each equation was corrected for bias as suggested by Baskerville (1972).

No mean residuals (bias) for either sweetgum or water oak predictions were significantly different from zero by the paired t test. The magnitude of bias is small in relation to the component means, ranging from 0.0 to 5.6 percent of the mean. These magnitudes are comparable to earlier sycamore results from this same study (Willson et al. 1982).

Stepwise regression is a suitable method for screening a large number of variables and gaining insight into variables that may be important biomass predictors. But many times automated stepwise routines are not available. Also, it would be desirable to use only a single model form if possible, or two at the most, to predict all biomass components for a single species. In the examples thus far, 62 models (and equations) were used, 31 each for sweetgum and water oak. All comparisons that follow are in relation to estimates from these 31 separate equations for each species.

REDUCING THE NUMBER OF MODELS

One of this paper's objectives is to determine if predictions from completely separate model forms could be added to estimate the total bole, total limb, and total tree values. This could possibly reduce the modeling effort from 31 to 14 equations. Willson et al. (1982) showed no significant mean bias when adding predictions using a common logarithmic model fitted to primary sycamore components. It seems logical that predictions from different model forms can also be added to give satisfactory results.

Component predictions using separate model forms can be added with no significant changes in mean residuals (bias) for either species (table 5). However, standard error was significantly increased in 6 of the 17 sweetgum predictions and significantly reduced in 8 of the 17 water oak predictions. Thus, predictions of primary components can be summed with no differences in mean totals, but there is a significant difference in the reliability of the estimate; variance and subsequent standard error can either increase or decrease.

Developing individual models for these 14 components is still a considerable task. Can a single model, or even several models, be selected that will fit the primary components? If so, how can they be selected to minimize modeling effort and still give satisfactory results?

There are several alternatives for choosing one or several model forms that will subsequently be used to fit all primary tree components. One method is to find the model that most accurately describes the tree component of highest proportion. For sweetgum this would be bole wood (64 (percent dry weight). Some precision will probably be lost if this model is used to predict all other components, but for practical purposes this

[3/] Minitab Inc., 215 Pond Laboratory, Pennsylvania State University, University Park, PA 16802.

Table 3.--Significant variables and fit statistics for fitting individual models to sweetgum tree component biomass using stepwise regression

Component	Sample mean	Significant variables[1/] 1	2	3	4	5	6	7	8	9	10	11	12	Fit index	Bias	Standard error	CV percent
							Green weight - lb										
Bole wood	14.72	X				X	X			X				0.963	-0.353	3.578	24.3
Bole bark	2.33	X								X		X		0.934	-0.047	0.661	28.4
Total bole	17.05						X	X		X	X			0.968	-0.332	3.794	22.3
Limb wood	4.84			X	X	X					X	X	X	0.850	-0.220	2.362	48.8
Limb bark	1.86					X	X	X			X	X		0.854	-0.094	0.833	44.8
Total limbs	6.70	X				X	X	X			X	X		0.899	-0.179	2.613	39.0
Tree wood	19.56	X					X	X		X	X	X		0.973	-0.345	4.031	20.6
Tree bark	4.19				X		X	X		X	X	X		0.934	-0.136	7.199	28.6
Tree w/o leaves	23.75	X			X		X	X		X	X	X		0.972	-0.427	4.876	20.5
Leaves	5.12			X		X	X						X	0.816	-0.001	2.554	49.9
Tree w/leaves	28.87						X			X	X			0.962	-0.566	6.654	23.1
							Dry weight - lb										
Bole wood	7.65					X	X	X		X	X			0.966	-0.188	1.774	23.2
Bole bark	0.97									X	X	X		0.949	-0.023	0.246	25.4
Total bole	8.62	X					X	X		X	X			0.980	-0.106	1.538	17.8
Limb wood	2.54		X	X				X		X	X		X	0.872	-0.098	1.150	45.3
Limb bark	0.81	X		X		X		X					X	0.827	-0.039	0.418	51.6
Total limbs	3.35		X	X		X		X			X		X	0.874	-0.125	1.489	44.5
Tree wood	10.19	X					X	X		X	X	X		0.973	-0.205	2.082	20.4
Tree bark	1.78						X	X		X	X			0.926	-0.059	0.553	31.2
Tree w/o leaves	11.97	X				X	X	X		X	X	X	X	0.968	-0.240	2.641	22.1
Leaves	1.83	X		X			X						X	0.558	-0.153	1.389	75.9
Tree w/leaves	13.80	X			X		X	X		X	X	X	X	0.966	-0.267	3.100	22.5
							Volume - cubic feet										
Bole wood	0.233	X					X	X		X	X			0.982	-0.003	0.038	16.4
Bole bark	0.049									X	X	X		0.948	-0.001	0.012	23.8
Total bole	0.282	X					X	X		X	X			0.984	-0.003	0.042	14.9
Limb wood	0.082		X	X				X		X	X		X	0.883	-0.003	0.034	42.0
Limb bark	0.044	X		X				X	X			X		0.791	-0.002	0.022	50.8
Total limbs	0.126	X				X	X	X			X	X		0.908	-0.004	0.045	35.8
Tree wood	0.315	X					X	X		X	X	X		0.981	-0.006	0.052	16.6
Tree bark	0.093						X	X	X	X	X	X		0.940	-0.003	0.024	25.8
Tree w/o leaves	0.408	X					X	X		X	X	X		0.980	-0.009	0.068	16.6

1/ 1 = D, 2 = H, 3 = N, 4 = A, 5 = Ln(D), 6 = Ln(N), 7 = $1/A^2$, 8 = D^2H, 9 = $Ln(D^2H)$, 10 = $[Ln(D^2H)]^2$, 11 = [Ln(N)]/A, 12 = N/A.

Table 4.--Significant variables and fit statistics for fitting individual models to water oak tree component biomass using stepwise regression

Component	Sample Mean	Significant variables[1/] 1	2	3	4	5	6	7	8	9	10	11	12	Fit index	Bias	Standard error	CV percent
								Green weight - lb									
Bole wood	8.41				X					X	X	X		0.971	0.006	1.798	21.4
Bole bark	1.77							X		X	X			0.881	-0.006	0.670	37.8
Total bole	10.18				X					X	X	X		0.973	-0.006	2.048	20.1
Limb wood	8.51	X					X		X					0.927	-0.406	3.692	43.4
Limb bark	1.77	X					X		X					0.891	-0.039	0.849	47.9
Total limbs	10.28	X					X		X					0.926	-0.403	4.403	42.8
Tree wood	16.92	X								X			X	0.756	-0.923	11.874	70.2
Tree bark	3.54	-						X	X					0.931	-0.058	1.151	32.5
Tree w/o leaves	20.46	X								X			X	0.747	-1.072	14.263	69.7
Leaves	3.80	X			X				X			X		0.757	-0.064	2.025	53.3
Tree w/leaves	24.26	X							X				X	0.941	-0.555	7.804	32.2
								Dry weight - lb									
Bole wood	4.83				X					X	X	X		0.972	-0.022	0.977	20.2
Bole bark	1.10									X	X	X		0.884	-0.020	0.435	39.4
Total bole	5.93				X					X	X	X		0.974	-0.039	1.141	19.2
Limb wood	5.30	X			X		X	X	X					0.892	-0.283	2.814	53.1
Limb bark	0.94	X					X		X					0.899	-0.027	0.430	45.6
Total limbs	6.24	X			X		X	X	X					0.896	-0.297	3.188	51.1
Tree wood	10.13	X								X			X	0.744	-0.564	7.145	70.6
Tree bark	2.04	X								X		X		0.742	-0.094	1.297	63.4
Tree w/o leaves	12.17	X								X			X	0.752	-0.661	8.276	68.0
Leaves	1.82	X			X		X		X					0.768	-0.032	0.919	50.5
Tree w/leaves	13.99	X					X	X	X	X				0.929	-0.330	4.933	35.3
								Volume - cubic feet									
Bole wood	0.123						X	X		X	X		X	0.979	-0.001	0.023	18.3
Bole bark	0.031										X	X	X	0.894	-0.000	0.011	35.2
Total bole	0.154				X					X	X	X		0.977	-0.001	0.029	18.6
Limb wood	0.127	X			X				X				X	0.910	-0.007	0.061	48.1
Limb bark	0.040	X							X					0.900	-0.001	0.017	43.0
Total limbs	0.167	X					X		X					0.936	-0.007	0.065	38.9
Tree wood	0.250	X								X			X	0.752	-0.014	0.176	70.5
Tree bark	0.071	X						X	X					0.942	-0.001	0.021	29.2
Tree w/o leaves	0.321	X								X			X	0.752	-0.017	0.218	68.1

1/ 1 = D, 2 = H, 3 = N, 4 = A, 5 = Ln(D), 6 = Ln(N), 7 = $1/A^2$, 8 = D^2H, 9 = $Ln(D^2H)$, 10 = $[Ln(D^2H)]^2$, 11 = [Ln(N)]/A, 12 = N/A.

Table 5.--Statistics produced by adding individual tree component predictions to produce total bole, total limbs, and total tree estimations for sweetgum and water oak

Component	Sweetgum Fit index	Sweetgum Bias	Sweetgum t for bias (df)	Sweetgum Std. error	Sweetgum Coef. var.	Water oak Fit index	Water oak Bias	Water oak t for bias (df)	Water oak Std. error	Water oak Coef. var.
				Green weight - lb						
Total bole	0.962	-0.399	-1.14 (122)	4.173	24.5	0.972	0.000	0.00 (102)	2.124	20.8
Total limbs	0.865	-0.315	-1.22 (118)	3.105+	46.4	0.927	-0.445	-1.09 (103)	4.483	43.6
Tree wood	0.956	-0.573	-1.33 (119)	5.196+	26.6	0.958	-0.400	-0.87 (102)	5.064*	29.9
Tree bark	0.921	-0.141	-1.26 (120)	1.328	31.7	0.929	-0.045	-0.41 (103)	1.194	33.7
Tree w/o leaves	0.955	-0.714	-1.37 (109)	6.565+	27.6	0.959	-0.445	-0.83 (94)	6.109*	29.8
Tree w/leaves	0.956	-0.715	-1.16 (104)	7.911+	27.4	0.949	-0.509	-0.75 (89)	7.950	32.8
				Dry weight - lb						
Total bole	0.966	-0.212	-1.26 (121)	2.005+	23.3	0.974	-0.042	-0.39 (102)	1.164	19.6
Total limbs	0.874	-0.136	-1.07 (118)	1.529	45.7	0.898	-0.309	-1.06 (101)	3.219	51.6
Tree wood	0.965	-0.286	-1.42 (118)	2.429	23.8	0.941	-0.305	-0.96 (100)	3.541*	35.0
Tree bark	0.917	-0.062	-1.24 (121)	0.597	33.6	0.935	-0.046	-0.76 (103)	0.664*	32.4
Tree w/o leaves	0.962	-0.348	-1.43 (108)	3.072	25.7	0.948	-0.351	-1.00 (92)	4.066*	33.4
Tree w/leaves	0.944	-0.501	-1.52 (103)	4.283+	31.1	0.939	-0.383	-0.91 (87)	5.003	35.8
				Volume - cubic feet						
Total bole	0.982	-0.004	-1.02 (121)	0.045	16.0	0.979	-0.002	-0.72 (101)	0.028	18.1
Total limbs	0.874	-0.005	-1.21 (118)	0.054+	42.9	0.917	-0.008	-1.18 (103)	0.075	44.9
Tree wood	0.981	-0.006	-1.33 (118)	0.054	17.0	0.955	-0.008	-1.21 (100)	0.078*	31.0
Tree bark	0.933	-0.003	-1.57 (121)	0.026	27.5	0.928	-0.001	-0.66 (104)	0.023*	33.1
Tree w/o leaves	0.979	-0.009	-1.61 (108)	0.073	17.8	0.958	-0.010	-1.18 (93)	0.096*	30.0

+ Standard error significantly ($\alpha = 0.05$) larger using the two-sided F test than that produced by separate prediction equation.

* Standard error significantly ($\alpha = 0.05$) smaller using the two-side F test than that produced by separate prediction equation.

makes little difference due to the relatively small proportions of these other components.

Should this single model be fitted to green weight, dry weight, or volume? Fitting to dry bole wood weight eliminates variation due to moisture content. Fitting to bole wood volume would be acceptable, since this also reduces variation due to wood density--but in biomass work, weight is the usual measurement unit of interest.

Water oak has no component of highest proportion; bole wood is 40 percent and limb wood 43 percent of the total tree. The options in this case are: (1) Develop a bole wood model and use it for all primary tree components, (2) develop a limb wood model and use it to fit all primary components, or (3) develop individual bole wood and limb wood models and fit each to their respective components.

To test this idea, the model was selected for sweetgum that best described dry bole wood weight:

$$\mathrm{Ln}(Y) = b_0 + b_1\mathrm{Ln}(D) + b_2\mathrm{Ln}(N) + b_3 1/A^2 + b_4\mathrm{Ln}(D^2H) + b_5[\mathrm{Ln}(D^2H)]^2 \quad (1)$$

This model was subsequently fit to each of the 10 tree weights (5 green and 5 dry) and 4 tree volume components; total bole, total limb, and total tree values were estimated by summing the predictions of the primary components. The component estimations and summed predictions were tested against predictions from the individual models shown in table 3. Prediction differences were compared using the paired t test; variances of the predictions were compared using the two-sided F test (table 6).

Table 6.--Comparing a bole wood model to individual component prediction models for predicting sweetgum biomass components

Component	Predicted mean[1/]	(df)	Estimated variance	Predicted means and summed predictions[2/]	(df)	Estimated variance	Mean difference	Variance ratio (largest/ smallest)	
				Green weight - lb					
Bole wood	15.07	(126)	12.80	15.02	(125)	10.44	0.05	1.23	
Bole bark	2.38	(127)	0.44	2.35	(125)	0.24	0.03	1.83	*
Total bole	17.38	(126)	14.39	17.37	(119)	13.41	0.01	1.07	
Limb wood	5.06	(124)	5.57	5.03	(125)	4.77	0.03	1.17	
Limb bark	1.95	(125)	0.69	1.92	(125)	0.57	0.03	1.21	
Total limbs	6.88	(124)	6.83	6.95	(119)	8.12	-0.07	1.19	
Tree wood	19.90	(124)	16.25	20.05	(119)	22.80	-0.15	1.40	+
Tree bark	4.33	(124)	1.44	4.27	(119)	1.14	0.06	1.26	
Tree w/o leaves	24.17	(123)	23.78	24.32	(107)	33.97	-0.15	1.43	+
Leaves	5.12	(126)	6.51	5.15	(125)	6.78	-0.03	1.04	
Tree w/leaves	29.43	(127)	44.28	29.47	(101)	59.01	-0.04	1.33	
				Dry weight - lb					
Bole wood	7.84	(125)	3.15	7.84	(125)	3.15	0.00	1.00	
Bole bark	0.99	(127)	0.06	0.99	(125)	0.08	0.00	1.33	
Total bole	8.72	(125)	2.36	8.83	(119)	4.22	-0.11	1.79	+
Limb wood	2.64	(124)	1.32	2.66	(125)	1.28	-0.02	1.03	
Limb bark	0.85	(125)	0.17	0.84	(125)	0.14	0.01	1.21	
Total limbs	3.47	(124)	2.22	3.50	(119)	2.21	-0.03	1.00	
Tree wood	10.39	(124)	4.33	10.49	(119)	6.86	-0.10	1.58	+
Tree bark	1.83	(126)	0.31	1.83	(119)	0.32	0.00	1.03	
Tree w/o leaves	12.20	(122)	6.97	12.32	(107)	10.67	-0.12	1.53	+
Leaves	1.98	(126)	1.93	1.84	(125)	0.82	0.14	2.35	*
Tree w/leaves	14.06	(122)	9.60	14.16	(101)	14.15	-0.10	1.47	+
				Volume - cubic feet					
Bole wood	0.236	(125)	0.00145	0.239	(125)	0.00302	-0.003	2.08	+
Bole bark	0.051	(127)	0.00014	0.051	(125)	0.00018	0.000	1.28	
Total bole	0.286	(125)	0.00177	0.290	(119)	0.00450	-0.004	2.54	+
Limb wood	0.085	(124)	0.00118	0.086	(125)	0.00117	-0.001	1.01	
Limb bark	0.046	(125)	0.00049	0.045	(125)	0.00031	0.001	1.58	+
Total limbs	0.130	(124)	0.00202	0.131	(119)	0.00240	-0.001	1.19	
Tree wood	0.321	(124)	0.00273	0.325	(119)	0.00560	-0.004	2.05	+
Tree bark	0.096	(124)	0.00058	0.096	(119)	0.00070	0.000	1.21	
Tree w/o leaves	0.417	(124)	0.00458	0.421	(107)	0.00970	-0.004	2.12	+

1/ Means predicted from individual models; these are slightly different from sample means presented in tables 1 and 3.

2/ Estimated from $Ln(Y) = b_0 + b_1 Ln(D) + b_2 Ln(N) + b_3 1/A^2 + b_4 Ln(D^2H) + b_5 [Ln(D^2H)]^2$.

* Variance of bole wood model equation significantly ($\alpha = 0.05$) smaller than variance of individual component equation using the two-sided F test.

\+ Variance of bole wood model equation significantly ($\alpha = 0.05$) larger than variance of individual prediction equation using the two-sided F test.

No significant differences in mean component predictions were found in estimating component biomass for sweetgum when using a single model fit to the primary tree components and then summing component predictions to estimate tree totals. However, prediction variance was significantly increased in 11 cases. Thus, while a component average of a large number of trees can be accurately determined using a single model form fit to all tree components, there is a significant lack of confidence in predicting the biomass of a specific tree.

Similar tests were also done for water oak. Since bole wood and limb wood occurred in about equal proportions, the best dry bole wood model:

$$Ln(Y) = b_0 + b_1A + b_2Ln(D^2H) + b_3[Ln(D^2H)]^2 + b_4[Ln(N)]/A, \quad (2)$$

and dry limb wood model:

$$Ln(Y) = b_0 + b_1D + b_2A + b_3Ln(N) + b_4(1/A^2) + b_5D^2H, \quad (3)$$

were each fit to the 10 tree weight components and 4 volume components. Predictions from each model were again compared to predictions from individual component models (given in table 4 for water oak). Individual tree predictions and mean bias were tested using the paired t test and variances compared with the F test.

Fitting the best dry bole wood model (eq. 2) to primary tree components, then summing predictions to estimate total bole, limb, and tree values, showed no significant differences in predicting the average tree component (table 7). But, as with sweetgum, prediction variance increased in nine cases and decreased in seven cases. Six of the nine increases are directly attributable to errors in using the bole wood model to predict limb components, indicating the bole wood model is not the "correct" model for predicting limbs. Variance for total tree predictions was significantly reduced.

Fitting the best dry limb wood model to the primary components gives no significant differences in estimating the average tree component, but some variances are significantly different from those individual component prediction models (table 8). Six of eight variance increases are for bole estimates, indicating that a limb model may not be "best" for predicting bole components. However, total limb variance is still significantly increased for green weight and volume.

Since limb prediction variance was increased using the bole model and bole prediction variance was increased using the limb model, the logical next step is to fit the bole model to bole components, the limb model to limb components, and a dry leaf model to the leaf components. This would give three separate model forms to fit to the three main tree components: boles, limbs, and leaves. Total bole, total limbs, and total tree estimates are obtained by summing individual predictions. These results are given in table 9.

No significant differences in estimating component means were noted. Although total limb green weight and volume prediction variances are still significantly larger than if a separate total limb prediction model had been used, all other variances are either unchanged or are significantly reduced.

SUMMARY AND CONCLUSIONS

Sweetgum and water oak trees sampled from a plantation over 7 years were used to test whether primary tree component predictions could be summed to estimate total bole, total limb, and total tree values. The primary predictors are: volume--bole wood, bole bark, limb wood, and limb bark; and green and dry weight--bole wood, bole bark, limb wood, limb bark, and leaves. Twelve independent variables were fitted using stepwise regression to give a separate prediction model for each primary component and each total bole, limb, and tree value. Mean tree estimates by summing primary component predictions were not significantly different from mean predictions for the total tree model, but prediction variances were increased for sweetgum and reduced for water oak.

An attempt was made to find a single model form for each species that would satisfactorily fit all primary components for each species. Fitting a bole wood model to all sweetgum components gave satisfactory estimates of component means, but prediction variance was significantly increased in a number of cases. Satisfactory results were obtained for water oak by fitting a bole wood model to primary bole components, a limb wood model to primary limb components, and a leaf model to leaf weights. Primary predictions and summations of these models showed no significant bias with prediction variance generally unchanged or reduced.

Due to the quite different results from these two species, it is not possible to infer results to other species. Growth characteristics seem to play an important role in these young plantations, particularly when estimating limb biomass.

The 12 independent variables used for model building and testing were screened from a larger set specifically for these 2 species. This was due to the limitations of the available computer hardware and software. Other species may require additional transformations or combinations of the four basic variables to give reliable component predictions. It appears that biomass prediction models for the other species in this plantation will have to be developed for each separate species to give the most reliable estimates.

Table 7.--Comparing a bole wood model to individual component prediction models for predicting water oak biomass components

Component	Predicted mean[1/]	(df)	Estimated variance	Predicted means and summed predictions[2/]	(df)	Estimated variance	Mean difference	Variance ratio (largest/smallest)
				Green weight - lb				
Bole wood	8.41	(106)	3.23	8.41	(106)	3.23	0.00	1.00
Bole bark	1.78	(107)	0.45	1.78	(106)	0.43	0.00	1.05
Total bole	10.19	(106)	4.19	10.19	(101)	4.43	0.00	1.06
Limb wood	8.92	(107)	13.63	8.56	(106)	20.20	0.36	1.48 +
Limb bark	1.81	(107)	0.72	1.77	(106)	1.07	0.04	1.49 +
Total limbs	10.69	(107)	19.39	10.33	(101)	31.10	0.36	1.60 +
Tree wood	17.85	(107)	140.99	16.96	(101)	37.03	0.87	3.81 *
Tree bark	3.60	(107)	1.32	3.56	(101)	1.99	0.04	1.51 +
Tree w/o leaves	21.54	(107)	203.43	20.52	(91)	57.37	1.02	3.55 *
Leaves	3.86	(106)	4.10	3.83	(106)	4.73	0.03	1.15
Tree w/leaves	24.83	(107)	60.90	24.35	(86)	94.85	0.48	1.55 +
				Dry weight - lb				
Bole wood	4.85	(106)	0.95	4.85	(106)	0.95	0.00	1.00
Bole bark	1.12	(107)	0.19	1.12	(106)	0.19	0.00	1.00
Total bole	5.97	(106)	1.30	5.97	(101)	1.37	0.00	1.05
Limb wood	5.58	(105)	7.92	5.32	(106)	8.87	0.26	1.12
Limb bark	0.97	(107)	0.18	0.95	(106)	0.30	0.02	1.67 +
Total limbs	6.54	(105)	10.16	6.27	(101)	12.68	0.27	1.25
Tree wood	10.69	(107)	51.05	10.17	(101)	14.58	0.52	3.50 *
Tree bark	2.14	(107)	1.68	2.07	(101)	0.64	0.07	2.62 *
Tree w/o leaves	12.83	(107)	68.49	12.24	(91)	21.35	0.59	3.21 *
Leaves	1.85	(106)	0.84	1.84	(106)	1.14	0.01	1.36
Tree w/leaves	14.32	(105)	24.33	14.08	(86)	32.87	0.24	1.35
				Volume - cubic feet				
Bole wood	0.125	(105)	0.00051	0.123	(106)	0.00060	0.002	1.18
Bole bark	0.031	(107)	0.00012	0.032	(106)	0.00011	-0.001	1.06
Total bole	0.155	(106)	0.00083	0.155	(101)	0.00090	0.000	1.08
Limb wood	0.134	(106)	0.00373	0.128	(106)	0.00407	0.006	1.09
Limb bark	0.041	(108)	0.00029	0.041	(106)	0.00042	0.000	1.45 +
Total limbs	0.174	(107)	0.00422	0.169	(101)	0.00700	0.005	1.66 +
Tree wood	0.264	(107)	0.03105	0.251	(101)	0.00730	0.013	4.25 *
Tree bark	0.072	(107)	0.00043	0.073	(101)	0.00070	-0.001	1.63 +
Tree w/o leaves	0.339	(107)	0.04774	0.324	(91)	0.01250	0.015	3.82 *

1/ Means predicted from individual models; these are slightly different from sample means presented in tables 1 and 4.

2/ Predicted from $Ln(Y) = b_0 + b_1A + b_2Ln(D^2H) + b_3[Ln(D^2H)]^2 + b_4[Ln(N)]/A$.

\+ Variance of bole wood model equation significantly (α = 0.05) larger than variance of individual component equation using the two-sided F test.

* Variance of bole wood model equation significantly (α = 0.05) smaller than variance of individual component equation using the two-sided F test.

Table 8.--Comparing a limb wood model to individual component prediction models for predicting water oak biomass components

Component	Predicted mean[1/]	(df)	Estimated variance	Predicted means and summed predictions[2/]	(df)	Estimated variance	Mean difference	Variance ratio (largest/smallest)	
				Green weight - lb					
Bole wood	8.41	(106)	3.23	8.70	(105)	5.29	-0.29	1.64	+
Bole bark	1.78	(107)	0.45	1.81	(105)	0.38	-0.03	1.18	
Total bole	10.19	(106)	4.19	10.51	(99)	6.73	-0.32	1.61	+
Limb wood	8.92	(107)	13.63	8.97	(105)	18.58	-0.05	1.36	
Limb bark	1.81	(107)	0.72	1.82	(105)	0.83	-0.01	1.15	
Total limbs	10.69	(107)	19.39	10.79	(99)	30.01	-0.10	1.55	+
Tree wood	17.85	(107)	140.99	17.67	(99)	33.42	0.18	4.21	*
Tree bark	3.60	(107)	1.32	3.63	(99)	1.34	-0.03	1.02	
Tree w/o leaves	21.54	(107)	203.43	21.30	(87)	51.33	0.24	3.96	*
Leaves	3.86	(106)	4.10	3.87	(105)	3.68	-0.01	1.11	
Tree w/leaves	24.83	(107)	60.90	25.17	(81)	83.25	-0.34	1.37	
				Dry weight - lb					
Bole wood	4.85	(106)	0.95	5.01	(105)	1.80	-0.16	1.89	+
Bole bark	1.12	(107)	0.19	1.16	(105)	0.21	-0.04	1.10	
Total bole	5.97	(106)	1.30	6.17	(99)	2.57	-0.20	1.98	+
Limb wood	5.58	(105)	7.92	5.58	(105)	7.92	0.00	1.00	
Limb bark	0.97	(107)	0.18	0.98	(105)	0.21	-0.01	1.17	
Total limbs	6.54	(105)	10.16	6.56	(99)	10.94	-0.02	1.08	
Tree wood	10.69	(107)	51.05	10.59	(99)	13.97	0.10	3.65	*
Tree bark	2.14	(107)	1.68	2.14	(99)	0.42	0.00	4.00	*
Tree w/o leaves	12.83	(107)	68.49	12.73	(87)	19.39	0.10	3.53	*
Leaves	1.85	(106)	0.84	1.85	(105)	0.89	0.00	1.06	
Tree w/leaves	14.32	(105)	24.33	14.58	(81)	29.26	-0.26	1.20	
				Volume - cubic feet					
Bole wood	0.125	(105)	0.00051	0.127	(105)	0.00107	-0.002	2.10	+
Bole bark	0.031	(107)	0.00012	0.032	(105)	0.00012	-0.001	1.00	
Total bole	0.155	(106)	0.00083	0.159	(99)	0.00150	-0.004	1.81	+
Limb wood	0.134	(106)	0.00373	0.134	(105)	0.00385	0.000	1.03	
Limb bark	0.041	(108)	0.00029	0.041	(105)	0.00027	0.000	1.07	
Total limbs	0.174	(107)	0.00422	0.175	(99)	0.00610	-0.001	1.45	+
Tree wood	0.264	(107)	0.03105	0.261	(99)	0.00730	0.003	4.25	*
Tree bark	0.072	(107)	0.00043	0.073	(99)	0.00040	-0.001	1.07	
Tree w/o leaves	0.339	(107)	0.04774	0.334	(87)	0.01140	0.005	4.19	*

1/ Predicted from individual models.

2/ Predicted from $Ln(Y) = b_0 + b_1D + b_2A + b_3Ln(N) + b_4(1/A^2) + b_5D^2H$.

+ Variance of limb wood model equation significantly ($\alpha = 0.05$) larger than variance of individual component equation using the two-sided F test.

* Variance of limb wood model equation significantly ($\alpha = 0.05$) smaller than variance of individual component equation using the two-sided F test.

Table 9.--Comparing predictions from bole wood model plus limb wood model to individual component prediction models for predicting water oak biomass components

Component	Predicted mean[1] (df)	Esti-mated variance	Predicted means and summed predictions[2] (df)	Esti-mated variance	Mean differ-ence	Variance ratio (largest/smallest)
			Green weight - lb			
Bole wood	8.41 (106)	3.23	8.41 (106)	3.23	0.00	1.00
Bole bark	1.78 (107)	0.45	1.78 (106)	0.43	0.00	1.05
Total bole	10.19 (106)	4.19	10.19 (101)	4.43	0.00	1.06
Limb wood	8.92 (107)	13.63	8.97 (105)	18.58	-0.05	1.36
Limb bark	1.81 (107)	0.72	1.82 (105)	0.83	-0.01	1.15
Total limbs	10.69 (107)	19.39	10.79 (99)	30.01	-0.10	1.55 +
Tree wood	17.85 (107)	140.99	17.38 (100)	31.33	0.47	4.50 *
Tree bark	3.60 (107)	1.32	3.60 (100)	1.52	0.00	1.15
Tree w/o leaves	21.54 (107)	203.43	20.98 (89)	47.33	-0.44	4.30 *
Leaves	3.86 (106)	4.10	3.88 (106)	3.43	-0.02	1.20
Tree w/leaves	24.83 (107)	60.90	24.86 (84)	76.21	-0.03	1.25
			Dry weight - lb			
Bole wood	4.85 (106)	0.95	4.85 (106)	0.95	0.00	1.00
Bole bark	1.12 (107)	0.19	1.12 (106)	0.19	0.00	1.00
Total bole	5.97 (106)	1.30	5.97 (101)	1.37	0.00	1.05
Limb wood	5.58 (105)	7.92	5.58 (105)	7.92	0.00	1.00
Limb bark	0.97 (107)	0.18	0.98 (105)	0.21	-0.01	1.17
Total limbs	6.54 (105)	10.16	6.56 (99)	10.94	-0.02	1.08
Tree wood	10.69 (107)	51.05	10.43 (100)	12.54	0.26	4.07 *
Tree bark	2.14 (107)	1.68	2.10 (100)	0.46	0.04	3.65 *
Tree w/o leaves	12.83 (107)	68.49	12.53 (89)	17.52	0.30	3.91 *
Leaves	1.85 (106)	0.84	1.85 (106)	0.84	0.00	1.00
Tree w/leaves	14.32 (105)	24.33	14.38 (84)	26.48	-0.06	1.09
			Volume - cubic feet			
Bole wood	0.125 (105)	0.00051	0.123 (106)	0.00060	0.002	1.18
Bole bark	0.031 (107)	0.00012	0.032 (106)	0.00011	-0.001	1.09
Total bole	0.155 (106)	0.00083	0.155 (101)	0.00090	0.000	1.08
Limb wood	0.134 (106)	0.00373	0.134 (105)	0.00385	0.000	1.03
Limb bark	0.041 (108)	0.00029	0.041 (105)	0.00027	0.000	1.07
Total limbs	0.174 (107)	0.00422	0.175 (99)	0.00610	-0.001	1.45 +
Tree wood	0.264 (107)	0.03105	0.257 (100)	0.00640	0.007	4.85 *
Tree bark	0.072 (107)	0.00043	0.073 (100)	0.00050	-0.001	1.16
Tree w/o leaves	0.339 (107)	0.04774	0.330 (89)	0.01040	0.009	4.59 *

1/ Predicted from individual models.

2/ Bole components predicted from: $Ln(Y) = b_0 + b_1A + b_2Ln(D^2H) + b_3[Ln(D^2H)]^2 + b_4[Ln(N)]/A$.
Limb components predicted from: $Ln(Y) = b_0 + b_1D + b_2A + b_3Ln(N) + b_4(1/A^2) + b_5D^2H$.
Leaf components predicted from: $Ln(Y) = b_0 + b_1D + b_2A + b_3Ln(N) + b_4D^2H$.

\+ Variance significantly ($\alpha = 0.05$) larger than variance of individual component equation using the two-sided F test.

* Variance significantly ($\alpha = 0.05$) smaller than variance of individual component equation using the two-sided F test.

Although no significant prediction bias was noted, mean residuals for both species were all negative. This suggests the Baskerville bias correction technique consistently overcorrected. Though these overcorrections are small, their effects are increased as components increase in size. This adds to prediction variance when converting from logarithmic units back to measured units. Perhaps more precise predictions could be obtained by correcting the bias for each equation so as to give a zero bias as suggested by Hepp and Brister (1982).

We would expect that as the plantation ages, the models for each species will become more similar. Crowns will close, limb mortality will become more rapid, and tree boles will increase in proportion. But in young plantations, different species will undoubtedly require different model forms to reliably estimate biomass.

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GEORGIA BIOMASS STUDY: PRELIMINARY RESULTS[1/]

JOHN B. TANSEY and NOEL D. COST[2/]

Abstract.--Estimates of total aboveground biomass associated with commercial forest land, noncommercial forest land, and nonforest land in Georgia are presented. Distribution of biomass on forest land is given by species group and by management and diameter classes; and on nonforest land, by specific land use and crown closure class. Available biomass is quantified for commercial forest land by recent stand history and treatment opportunity. Rate of accumulation of forest biomass in stands in relation to broad management type and stand age is also presented.

INTRODUCTION

In the past, State and regional forest inventories in the Southeast have been designed to estimate the merchantable volume (volume between a 1-foot stump and 4.0 inches d.o.b.) in growing-stock trees 5.0 inches d.b.h. and larger on commercial forest land. Because of increased interest in woody biomass as a source of energy, the amount of additional wood and bark in all trees (including saplings between 1.0-inch and 4.9-inches d.b.h.) on commercial forest land has become more important. Furthermore, the availability of aboveground biomass on noncommerical forest and nonforest land presents the opportunity to extend the "traditional" supplies of wood present in commercial forests. Forest Inventory and Analysis (FIA), in response to this growing interest, has expanded its sampling scheme to include both noncommerical forest and nonforest land so that estimates of total available biomass might be made on a statewide basis.

Forest biomass is defined as the aboveground green weight of wood and bark in all live trees 1.0-inch d.b.h. and larger, from the ground to the tip of the tree. All foliage is excluded. The weight of wood and bark in lateral limbs, secondary limbs, and twigs less than 0.5 inch in diameter at the point of occurrence on sapling-size trees is included, but is excluded on poletimber and sawtimber-size trees.

This paper contains estimates of total woody biomass on commercial and noncommerical forest land and nonforest land in Georgia. The rate at which forest biomass accumulates over time on commercial forest land is observed by broad management class. A comparison is made between the biomass available from convential growing stock and the biomass in all live timber, and the total biomass on commercial forest land is stratified by species groups and tree components. The unutilized sources of forest biomass are quantified in (1) recently harvested areas where much wood is left as residues, and (2) stands in need of regeneration.

INVENTORY DESIGN

The fifth forest inventory of the State of Georgia began in May 1980 and was completed in January 1983. This inventory was somewhat different from previous inventories in that it provided the data necessary for a complete statewide biomass analysis of Georgia's forest and nonforest land. The method of inventory is a sampling procedure designed to provide reliable area, volume, growth, and removal statistics primarily at the State and survey unit levels. Since guidelines were lacking for degree of precision or number of samples needed for biomass inventories, the evaluation presented here is for the entire State to minimize sampling errors. FIA was in a favorable position to conduct this statewide assessment because of its set of permanent sample plots uni-

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formly scattered across all forest (both commercial and noncommercial) and nonforest areas in the Southeast.

Within commercial and noncommercial forests, numbers of trees, sizes, and quality were recorded at each sample plot. Trees 5.0 inches d.b.h. and larger were measured at 3 to 5 points where variable-radius plots were defined by a basal area factor of 37.5. Trees less than 5.0 inches d.b.h. were tallied on 1/300-acre plots around the point centers. Biomass measurements were recorded at 7,084 commercial forest sample locations and 73 noncommercial forest sample locations across the State.

From a crown closure stratification of all nonforest plots, a subsample of 758 sample locations representing different closure classes and land uses were visited on the ground. At each location, number of trees 1.0 inch d.b.h. and larger associated with nonforest uses or occurring in narrow stringers and small patches of forest land not qualifying as commercial forest land were recorded on a 1-acre circular plot. These sample counts were expanded to represent the total population of trees on land classified as forest and nonforest. Volume equations based on detailed measurements of standing and felled trees in Georgia and on similar measurements taken from other trees throughout the Southeast were used to compute merchantable and total cubic volume (Cost 1978). Weight equations provided by the Utilization of Southern Timber Research Unit of the Southeastern Forest Experiment Station in Athens, Georgia, made it possible to convert volume to weight. The procedures used for collecting and reporting detailed biomass were outlined by Saucier (1979) and Clark (1979).

AREA AND DISTRIBUTION OF TOTAL BIOMASS BY LAND CLASS

Georgia encompasses 37.2 million acres of land area of which about 65 percent is classified as forest and about 35 percent as nonforest. The forest area is further divided into two categories: (1) commercial forest, and (2) noncommercial forest (fig. 1). Commercial forest land is defined as land at least 16.7 percent stocked by forest trees of any size, or formerly having had such tree cover, not currently developed for nonforest use, capable of producing 20 cubic feet of industrial wood per acre per year, and not withdrawn from timber utilization by legislative action. Noncommercial forest can be of two types: (1) productive-reserved forest land, which is land sufficiently productive to qualify as commercial forest, but withdrawn from timber utilization through statute or administrative designation, or (2) unproductive forest land, which is forest land incapable of producing 20 cubic feet of industrial wood per acre per year under natural conditions.

In Georgia there is a total of 1.8 billion tons of woody biomass. Ninety-five percent of the wood and bark biomass is on commercial forest land.

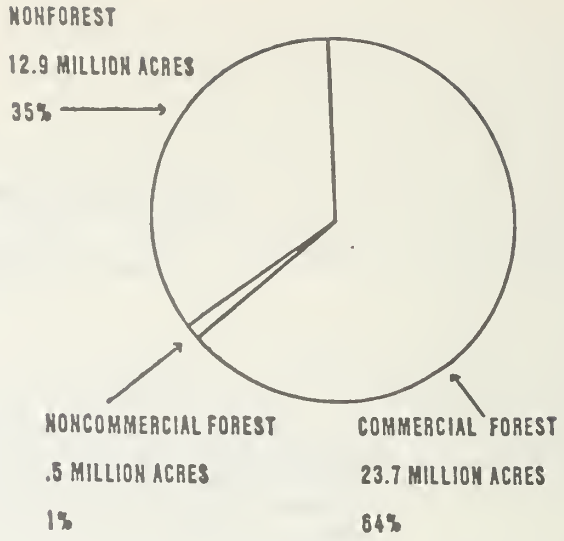

Figure 1.--Area by land class, Georgia, 1982.

About 46 million tons, or 3 percent, is associated with nonforest land uses; and 42 million tons, or 2 percent of the total, is on noncommerical forest land (fig. 2).

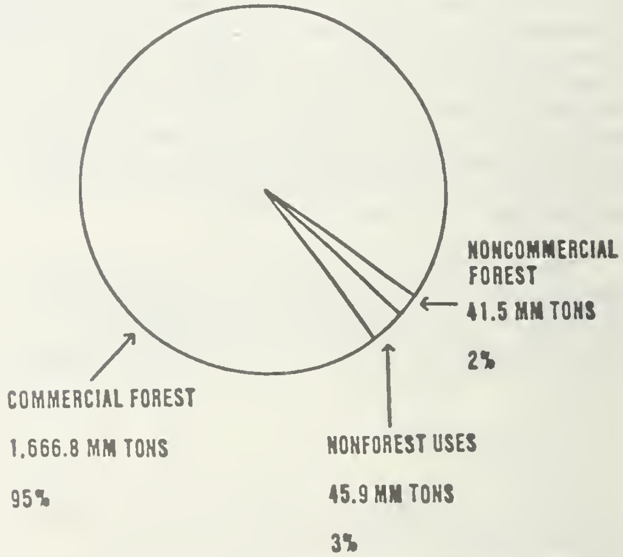

Figure 2.--Distribution of the green weight of aboveground tree biomass, by land class, Georgia, 1982.

BIOMASS ON COMMERICAL FOREST LAND

Georgia has more forest biomass on commercial forest land than any of the 12 Southern States--a total of 1.7 billion tons (fig. 3). North Carolina and Alabama follow closely.

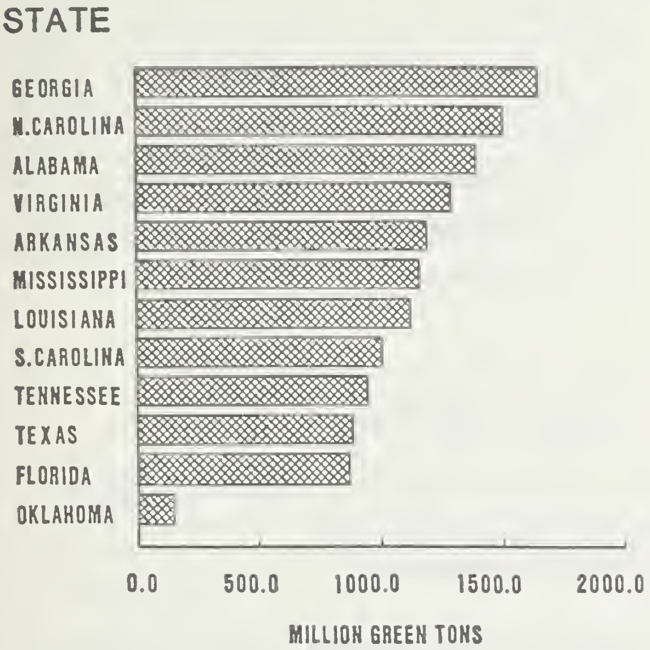

Figure 3.--Total green weight of aboveground tree biomass on commercial forest land, by State.

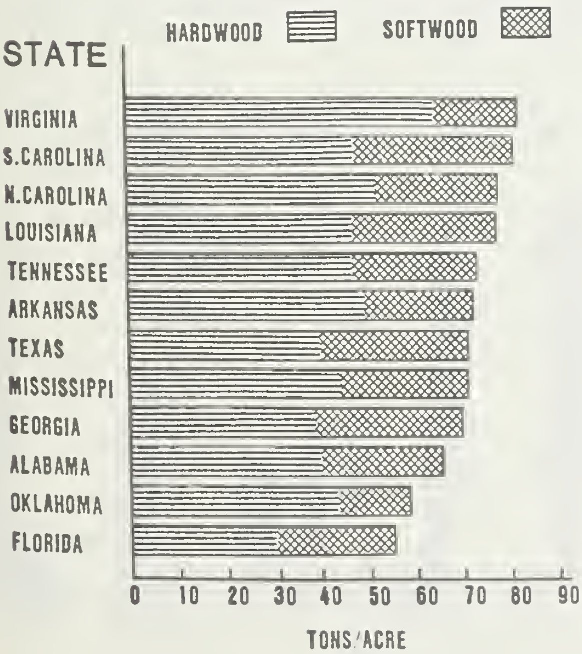

Figure 4.--Green weight per acre of aboveground tree biomass on commercial forest land, by State.

Average amounts of biomass per acre vary considerably by State, and in the South range from a low of less than 55 tons per acre in Florida, to a high of nearly 80 tons per acre in Virginia (fig. 4). For all 12 Southern States, green weight of forest biomass per acre averages 72 tons. In relation to other States, Georgia ranks ninth, with an average of 70 tons per acre. Several factors contribute to this variation in weight per acre, some of these being stand age, species composition, stocking, and site productivity. In Florida, where biomass weight per acre is low, more than half of the woody material is softwood. In Virginia, more than three-fourths of the biomass is hardwood, and many of the hardwood stands are not managed for high timber production.

Biomass Distribution by Broad Management Class

A compilation of acreage of commercial forest land, by broad management and stand age classes,* provides a good basis for examining the quantity, composition, distribution, and prospective availability of woody biomass in Georgia.

By broad management class, natural pine stands make up one-third of the commerical forest land area in Georgia and contain 36 percent of the biomass. Upland hardwood stands constitute 24 percent of the commercial forest area and account for 24 percent of the biomass. Both lowland hardwood stands and pine plantations account for 15 percent of the commercial forest area, but lowland hardwood stands compose 21 percent of the biomass, and pine plantations only 8 percent. Finally, oak-pine stands make up 13 percent of the commercial forest area and contain 11 percent of the biomass (fig. 5).

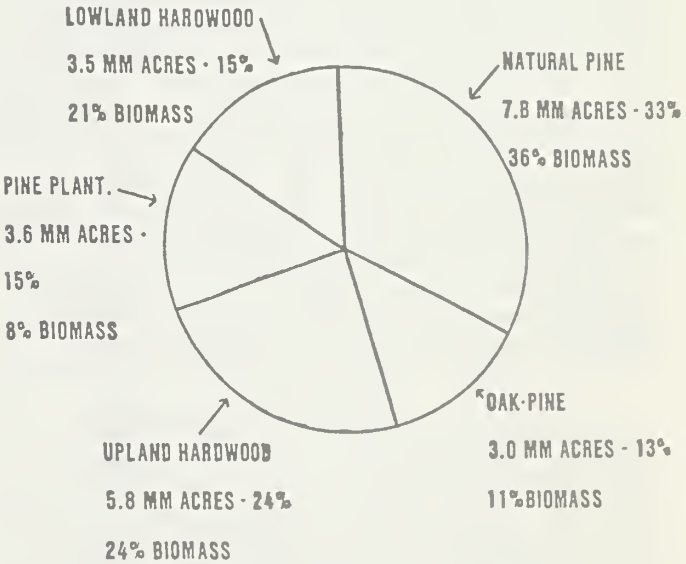

Figure 5.--Area of commercial forest land and forest biomass distribution, by broad management class, Georgia, 1982.

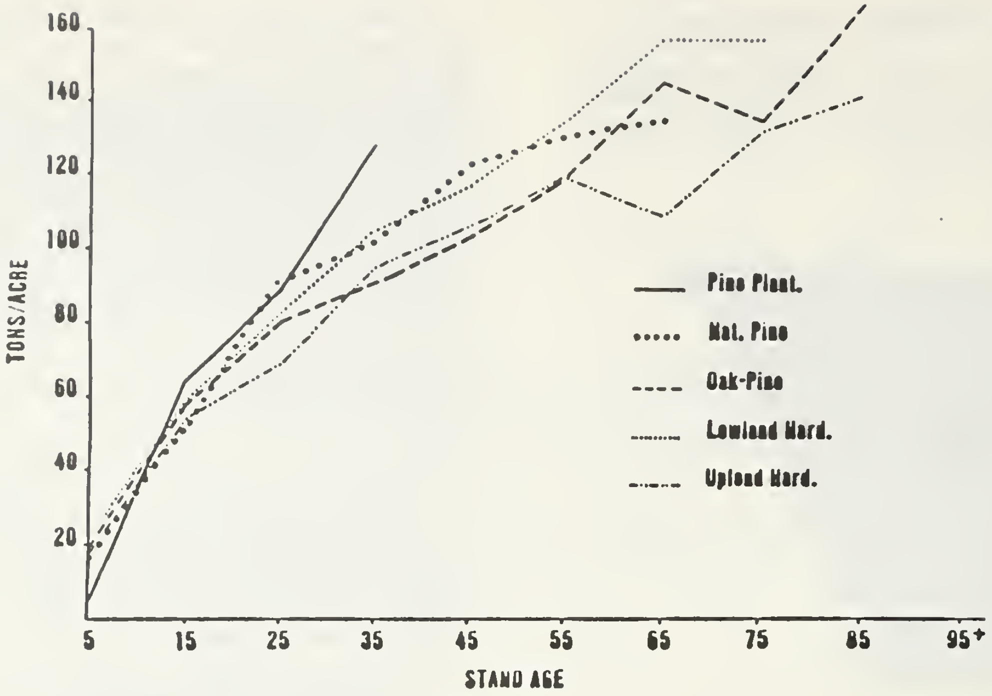

Figure 6.--Accumulation of forest biomass on commercial forest land in Georgia, by broad management class and stand age.

This indicates that, across all ages, the green weight of forest biomass per acre is greatest in lowland hardwood stands and least in pine plantations.

Figure 6 provides estimates of the average accumulation of biomass within each broad management class over time. Natural pine, oak-pine, lowland hardwood, and upland hardwood stands all exceed pine plantations in the total amount of woody biomass present before age 12. Part of this can be explained by the fact that pine plantations have fewer residual trees standing after harvesting operations. However, up to age 15, pine plantations accumulate biomass at a much faster rate than other types, so that by this age, the biomass per acre in pine plantations exceedes that in all other broad management classes. The rate of accumulation slows somewhat between 15 and 25 years. During this time, the rate of accumulation in natural pine stands and lowland hardwood stands exceeds that in pine plantations. Seemingly, beyond age 25, woody biomass accumulates much faster in intensively managed pine plantations than in other broad management types.

Across all age classes, the average green weight of forest biomass in pine plantations is 38.6 tons per acre. This low overall average is attributed to the large proportion (98 percent) of these stands that are less than 30 years old. On the other hand, the average weight of woody biomass in lowland hardwood stands is 97.0 tons per acre. More than 71 percent of the lowland hardwood stands in Georgia are 30 years old or older. A relatively low production of biomass in oak-pine stands (61.7 tons per acre) can be attributed in part to the origin of many of these stands. A large portion of these acres are sparsely stocked upland sites, a condition created after the harvest of former pine stands. The average green weight of woody biomass in upland hardwood stands is 70.0 tons per acre, and in natural pine stands, 76.0 tons per acre.

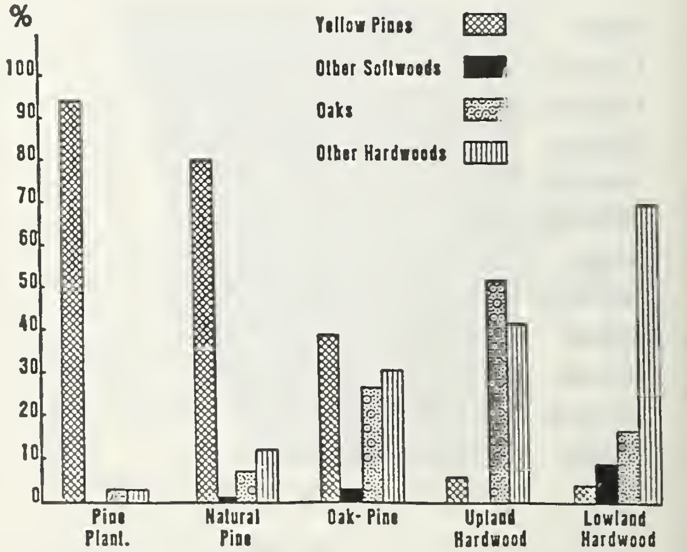

Figure 7.--Distribution of the green weight of forest biomass, by broad management class and species group, Georgia, 1982.

Species Distribution by Management Class

The distribution of the green weight of forest biomass by species group differs significantly within each broad management class (fig. 7). On the 7.8 million acres of natural pine stands across the State, more than 19 percent of the biomass is hardwood. In pine plantations, despite the intensive site preparation which is usually done in these stands, hardwoods make up 6 percent of the forest biomass. In oak-pine stands, hardwoods generally constitute about 60 percent of the stocking, and pines about 40 percent. In both upland and lowland hardwood stands, hardwoods make up around 90 percent of the total biomass. In lowland hardwood stands, other softwoods--primarily cypress--account for just under 10 percent of the biomass.

Size Distribution by Management Class

Hardwood, natural pine, and oak-pine stands all keep pace with more intensively managed pine plantations in total biomass production up to age 15. Diameter distribution within these stands gives some indication why this occurs (table 1). More than 65 percent of the total biomass in pine plantations 0-10 years in age is in trees less than 5.0 inches d.b.h. On the average, only 25 percent of the trees in all other broad management classes are in the smallest size classes. In upland and lowland hardwood stands, and in oak-pine stands, 23, 27, and 21 percent, respectively, of the biomass in stands age 0-10 years is in trees greater than 13.0 inches d.b.h. As mentioned, this biomass is in residual trees left after harvests of former stands.

Table 1.--Percent distribution of the average green weight of forest biomass per acre of commercial forest land, by broad management, tree diameter, and stand age classes, Georgia, 1982

Broad management and diameter classes (inches)	Stand age class (years)										
	All age classes	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91+
	Percent										
Pine plantation:											
1.0 - 4.9	18	65	27	8	2	5	--	--	--	--	--
5.0 - 8.9	50	25	61	46	14	9	--	--	--	--	--
9.0 - 12.9	27	3	11	39	56	41	--	--	--	--	--
13.0+	5	7	1	7	28	45	--	--	--	--	--
All classes	100	100	100	100	100	100	--	--	--	--	--
Natural pine:											
1.0 - 4.9	12	25	27	16	11	8	7	8	8	7	9
5.0 - 8.9	27	32	39	36	27	17	14	13	9	12	6
9.0 - 12.9	33	24	22	33	36	32	31	26	20	18	--
13.0+	28	19	12	15	26	43	48	53	63	63	85
All classes	100	100	100	100	100	100	100	100	100	100	100
Oak pine:											
1.0 - 4.9	16	24	30	23	16	11	11	11	8	10	7
5.0 - 8.9	25	27	28	32	29	23	18	18	15	19	7
9.0 - 12.9	27	28	20	28	28	27	26	30	30	20	26
13.0+	32	21	22	17	27	39	45	41	47	51	60
All classes	100	100	100	100	100	100	100	100	100	100	100
Upland hardwood:											
1.0 - 4.9	13	25	30	22	14	11	9	9	6	5	6
5.0 - 8.9	21	28	27	30	25	21	15	14	11	13	8
9.0 - 12.9	26	24	21	27	31	28	26	23	17	18	13
13.0+	40	23	22	21	30	40	50	54	66	64	73
All classes	100	100	100	100	100	100	100	100	100	100	100
Lowland hardwood:											
1.0 - 4.9	11	26	37	24	14	9	7	6	6	5	6
5.0 - 8.9	19	24	27	31	26	19	16	13	12	13	10
9.0 - 12.9	25	23	19	24	30	27	26	23	17	25	24
13.0+	45	27	17	21	30	45	51	58	65	57	60
All classes	100	100	100	100	100	100	100	100	100	100	100

Species Distribution of Aboveground Tree Biomass

In Georgia, hardwoods make up 54 percent of the forest biomass on commercial forest land (fig. 8). Oaks account for 39 percent of the hardwood total. Softwoods account for just under half of the woody biomass, or 46 percent. Loblolly pine is the most predominant softwood, accounting for 41 percent of the softwood total; slash pine accounts for 30 percent.

Average Green Weight of Conventional Growing Stock and Total Biomass

One of the major objectives of this study is to determine the proportion of total biomass, including bark, that is not considered to be conventional growing stock. Weight of conventional growing stock is the weight of wood and bark associated with bole portions of growing-stock trees 5.0 inches d.b.h. and larger, from a 1-foot stump to a 4.0-inch top d.o.b. For the 23.7 million acres classified as commercial forest land in Georgia, green weight of conventional growing stock averaged 46.7 tons per acre (table 2). Green weight of total biomass averaged 70.2 tons per acre, or 50 percent more than conventional growing stock. By broad management class, the largest difference between average weight of conventional growing stock and total woody biomass per acre was found in hardwood stands. In upland hardwood stands, average weight of total biomass exceeded the average weight of conventional growing stock by 26 tons per acre, or by 60 percent. In lowland hardwood stands, the difference averaged more than 35 tons per acre.

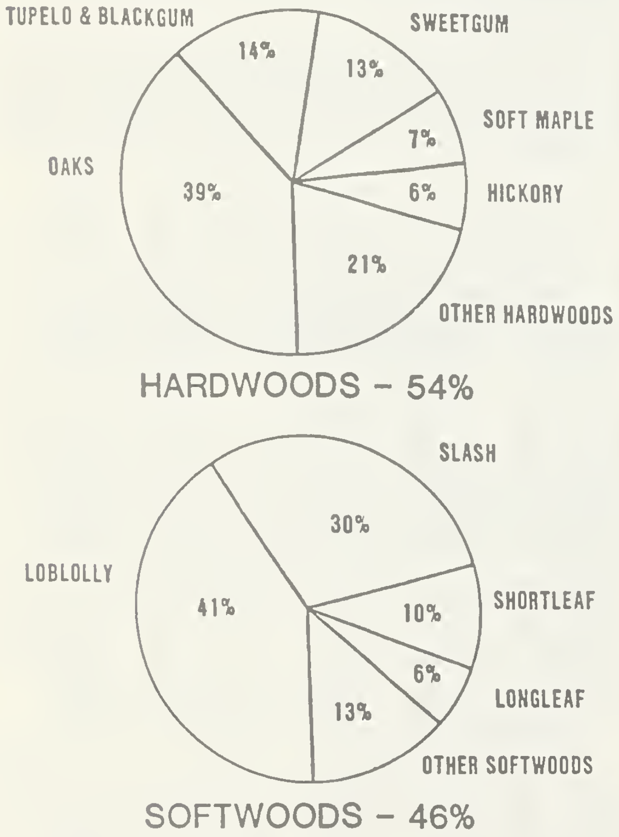

Figure 8.--Distribution of the green weight of forest biomass, by species, Georgia, 1982.

Table 2.--Average green weight of conventional growing stock and total forest biomass per acre of commercial forest land, by broad management class, Georgia, 1982

Broad management class	Conventional growing stock	Total biomass	Difference	
	- - Tons/acre - -		Tons/acre	Percent
Pine plantation	25.4	38.6	13.2	52
Natural pine	54.8	76.0	21.2	39
Oak-pine	39.1	61.7	22.6	58
Upland hardwood	43.8	70.0	26.2	60
Lowland hardwood	61.8	97.0	35.2	57
All classes	46.7	70.2	23.5	50

Table 3 compares the relationship between growing-stock biomass and total forest biomass among major species groups. Georgia's commercial forest land supports 1,666.8 million tons of woody biomass. Across all species, growing-stock trees account for 91 percent of this total. This ranges from a high of 99 percent in yellow pine to a low of 61 percent in other hardwoods. The remaining 9 percent is in trees 1.0 inch d.b.h. and larger which failed to meet minimum standards for growing stock because of species, poor form, or cull. About 44 percent of the forest biomass in these trees is in the bole portion of trees 5.0 inches d.b.h. and larger, and could be harvested with conventional equipment. The remainder, 15 percent in stumps,

Table 3.--Green weight and percent distribution of forest biomass on commercial forest land, by species group and biomass component, Georgia, 1982

Biomass component	All species	Species group: Yellow pine	Other softwood	Soft hardwood	Oaks	Other hardwoods
	- - - - - - - - - Percent of green weight - - - - - - - - -					
Growing stock:						
Bole	66.5	76.9	68.6	60.6	62.0	39.2
Stumps, tops, and limbs	14.5	14.3	19.3	13.1	17.2	10.1
Saplings	9.6	8.1	9.1	13.0	7.9	12.0
Total	90.6	99.3	97.0	86.7	87.1	61.3
Rough & rotten:						
Bole	4.1	.3	1.7	6.0	6.8	12.6
Stumps, tops and limbs	1.4	.1	.8	1.9	2.4	5.1
Saplings	3.9	.3	.5	5.4	3.7	21.0
Total	9.4	.7	3.0	13.3	12.9	38.7
All classes	100.0	100.0	100.0	100.0	100.0	100.0
Green weight (million tons)	1,666.8	720.0	51.5	403.6	363.1	128.6

Table 4.--Area of commercial forest land, by recent past treatment or disturbance and by broad management class, Georgia, 1982

Recent past treatment or disturbance[A]	All management classes	Broad management classes				
		Pine plantation	Natural pine	Oak-pine	Upland hardwood	Lowland hardwood
	Acres					
Harvesting	5,080,743	1,205,662	957,055	790,946	1,509,228	617,852
Commercial thinning	710,796	365,897	265,745	27,767	28,623	22,764
Artificial planting	404,156	366,525	0	24,536	13,095	0
Natural disturbance	3,771,356	734,787	1,483,314	331,802	714,560	506,893
Other[B]	4,495,187	430,952	2,065,049	578,962	941,574	478,650
None	9,271,445	488,332	3,075,601	1,205,537	2,598,177	1,903,799
All stands	23,733,684	3,592,155	7,846,764	2,959,550	5,805,257	3,529,958

[A]Primary treatment or disturbance of the stand between 1972 and 1982.

[B]Includes cleaning, release, grazing, draining, prescribed burning, site preparation, and other miscellaneous treatments.

tops, and limbs, and 41 percent in sapling-size trees, would require more specialized harvesting methods. The 10 percent forest biomass in growing-stock saplings is not available for energy wood, as this is needed to replace current growing-stock supplies.

Living Residues

Throughout Georgia, there are two major sources where wood suitable for energy is readily available: (1) recently harvested areas where much wood is left as residues, and (2) stands in need of regeneration.

As part of the fifth inventory in Georgia, field crews noted at each sample location the primary treatment or disturbance that occurred between 1972 and 1982. Some 14 million acres experienced significant treatment or disturbance, and timber harvesting was the most common forestry activity observed (table 4). On the average, slightly more than 499,000 acres were harvested annually, exclusive of intermediate cutting, commercial thinning, and land clearing.

Average Green Weight of Forest Biomass Per Acre of Commercial Forest Land by Recent Past Treatment

Green weight of forest biomass on harvested commercial forest land averages 23.3 tons per acre (table 5). By broad management class, average weight of forest biomass that was left after harvesting ranged from 3.6 tons per acre in pine plantations to 45.6 tons per acre in lowland hardwood stands. This 23.3 tons of forest biomass per acre includes only material left as living trees greater than 5.0 inches d.b.h. Stumps, tops, and limbs of the cut trees left as logging residues, as well as saplings, are excluded.

In these harvested stands, there is an average of 355 stems per acre. More than 85 percent of

Table 5.--Average green weight of forest biomass per acre of commercial forest land, by recent past treatment or disturbance and by broad management classes, Georgia, 1982

Recent past treatment or disturbance[A]	All management classes	Broad management classes				
		Pine plantation	Natural pine	Oak-pine	Upland hardwood	Lowland hardwood
	Tons/acre					
Harvesting	23.3	3.6	22.3	25.3	29.6	45.6
Commercial thinning	73.2	67.9	80.5	63.0	67.9	91.6
Artificial planting	11.8	12.7	0	3.3	5.3	0
Natural disturbance	86.9	70.5	94.0	71.2	81.5	107.6
Other[B]	72.6	61.2	74.8	65.2	68.9	89.4
None	90.3	54.7	84.5	82.4	91.1	112.9
All stands	70.2	38.5	76.0	61.7	70.0	97.0

[A]Primary treatment or disturbance of the stand between 1972 and 1982.

[B]Includes cleaning, release, grazing, draining, prescribed burning, site preparation, and other miscellaneous treatments.

these stems are between 1.0 and 5.0 inches d.b.h. (fig. 9). Seventy percent of the biomass in trees 1.0 inch d.b.h. and larger is composed of hardwood species (fig. 10). Practically all of these stands are the result of a harvest in which many poor-quality trees were left standing.

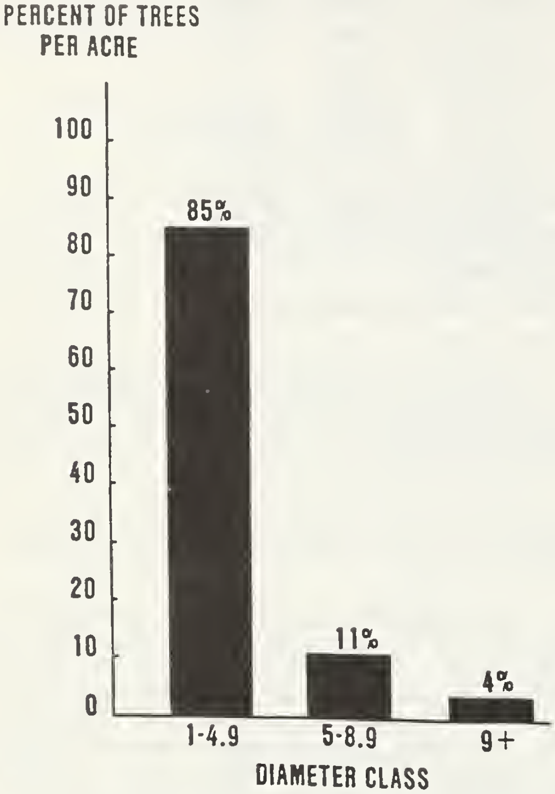

Figure 9.--Distribution of living residues in harvested stands, by diameter class, Georgia, 1982.

Average Green Weight of Forest Biomass Per Acre of Commercial Forest Land by Treatment Opportunity

At each sample location, field crews also noted any obvious opportunities for increasing prospective timber growth on sample plots. Commercial forest plots that are in need of regeneration represent the second major source of energy wood in Georgia. There are 4.0 million acres of commercial forest in Georgia too poorly stocked with acceptable trees to manage for timber production (table 6). These acres represent a backlog of needed regeneration on manageable sites. These

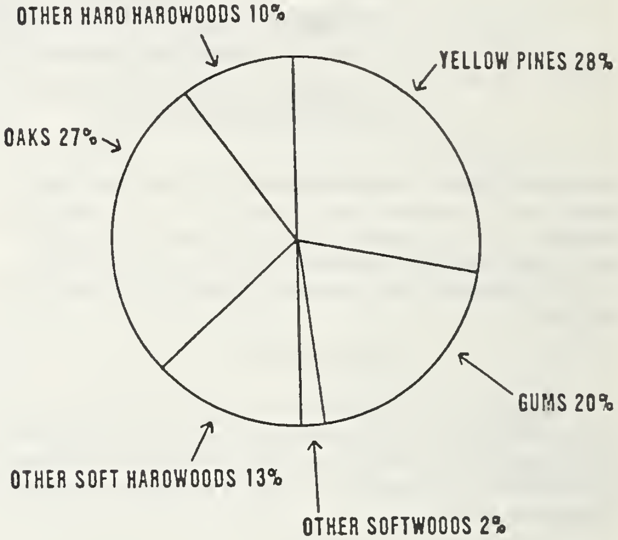

Figure 10.--Distribution of living residues in harvested stands, by species, Georgia, 1982.

Table 6.--Area of commercial forest land, by treatment opportunity and broad management classes, Georgia, 1982

Treatment opportunity class	All management classes	Broad management classes				
		Pine plantation	Natural pine	Oak-pine	Upland hardwood	Lowland hardwood
	Acres					
Salvage	248,917	100,039	80,374	16,790	25,490	26,224
Harvest	1,109,988	6,514	340,576	101,410	262,663	398,825
Comm. thinning	1,146,623	364,289	696,442	14,587	26,198	45,107
Other stand Imp.	2,342,322	125,272	694,917	487,815	692,320	341,998
Stand conversion	313,154	13,225	31,232	64,346	145,462	58,889
Regeneration	4,005,683	86,406	1,113,473	661,519	1,492,473	651,812
None[A]	13,063,803	2,886,460	4,752,778	1,437,157	2,562,742	1,424,666
Adverse sites	1,503,194	9,950	135,972	175,926	597,909	582,437
All stands	23,733,684	3,592,155	7,846,764	2,959,550	5,805,257	3,529,958

[A]Immature stands sufficiently stocked with growing-stock trees relatively free from damage or competition.

Table 7.--Average green weight of forest biomass per acre of commercial forest land, by treatment opportunity and broad management classes, Georgia, 1982

Treatment opportunity class	All management classes	Broad management classes				
		Pine plantation	Natural pine	Oak-pine	Upland hardwood	Lowland hardwood
	Tons/acre					
Salvage	87.4	78.3	86.2	99.7	85.6	118.9
Harvest	140.4	114.2	127.9	132.8	141.3	152.9
Comm. thinning	120.5	102.0	128.4	106.3	134.0	144.9
Other stand Imp.	63.5	47.4	59.1	63.8	60.0	85.1
Stand conversion	43.1	18.3	59.8	35.0	38.7	59.4
Regeneration	29.3	13.2	22.6	28.6	31.1	36.9
None[A]	69.8	29.1	77.8	69.1	82.5	103.2
Adverse sites[B]	103.2	4.1	109.4	80.1	95.7	117.1
All stands	70.2	38.6	76.0	61.7	70.0	97.0

[A]Immature stands sufficiently stocked with growing-stock trees relatively free from damage or competition.

[B]Areas where harvesting and timber management opportunities are severely limited because of either steep slopes or water problems.

acres in need of regeneration contain an average of 29.3 tons of forest biomass per acre (table 7). As in harvested stands, much of the biomass here is in rough, rotten, and other low-quality trees.

On the average, these stands have 349 trees per acre. More than 82 percent of the living residues are between 1.0 to 5.0 inches d.b.h., and two-thirds of the biomass is in hardwoods (fig. 11). The forest biomass on these poorly stocked acres represents about 7 percent of the total forest biomass in the State. Practically all of this biomass could be removed and used for energy wood without adversely affecting prospective timber supplies for the wood-using industries.

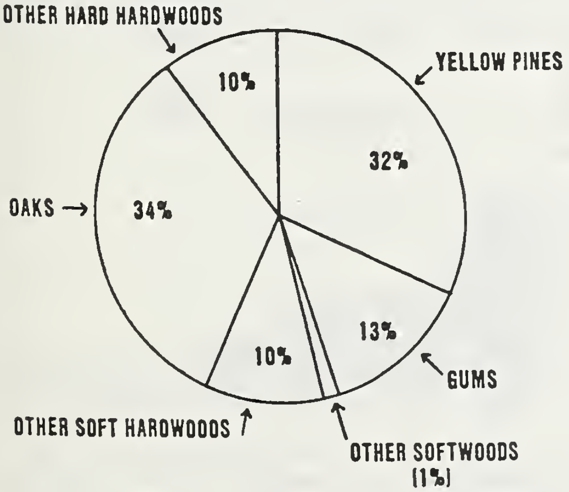

Figure 11.--Species distribution in stands needing regeneration, Georgia, 1982.

Another 300,000 acres support a manageable stand but will contribute very little net annual growth over the next decade unless converted and stocked with species more suitable to the sites.

Such areas contain an average of 43.1 tons of forest biomass per acre. With such a low average for biomass, it is doubtful that a harvest is economically feasible, so the cost of any cultural operation must be justified primarily on the basis of improved production in the new stand.

About 249,000 acres supported stands that need to be salvaged and regenerated. These stands contain substantial volume of merchantable timber seriously damaged by fire, insects, disease, wind, ice, or other destructive agents. Woody biomass on these stands averages 87.4 tons per acre.

About 64 percent of the forest biomass in Georgia is in stands either in good condition needing no treatment or in stands growing on sites limited by excessive slope or year-round water problems. This means that 36 percent of the forest biomass in Georgia is in stands where prospective energy wood could be harvested in harmony with conventional forestry practices and opportunities for enhancing future timber growth.

Total Energy Wood in Georgia

With a few reasonable assumptions, an estimate can be made of the amount of woody biomass in Georgia's commercial forests that could be removed for energy wood annually.

The 4.0 million acres of poorly stocked timber land classified as offering a regeneration opportunity are the primary source of energy wood that could be harvested without adversely affecting

prospective timber supplies. As shown, these sites support 29.3 tons of biomass per acre. If 5 percent of this acreage (200,284) were cleared each year, an estimated 5.9 million tons of energy wood could be harvested annually from these lands (table 8).

Table 8.--Energy wood available from commercial forest land in Georgia

Sources of energy wood	Acres	Biomass per acre	Total biomass	Annual harvest of energy wood
	Thousands	Tons	- - - Million tons - - -	
Stands needing regeneration	4,005.7	29.3	117.4	5.9
Living residues in harvested stands	499.4	23.3	11.6	11.6
Logging residues in harvested stands	499.4	21.1	10.5	10.5
All sources				28.0

Each year about 499,000 acres in Georgia experience a final harvest. An estimated 23.3 tons of woody biomass per acre are left standing following these harvests in the form of "living residues." This indicates there is an additional 11.6 million tons of energy wood available annually from harvested stands in standing material.

Based on FIA plot remeasurement data and utilization studies, it is estimated that the weight of logging slash and logging residues remaining in harvested stands in Georgia is equivalent to 21.1 tons per acre. Conventional logging residues are the unused merchantable portion of growing-stock trees cut or destroyed during logging operations, and represent about 31 percent of the total, or 6.5 tons per acre. Logging slash is the unmerchantable portion of growing-stock trees (including saplings) plus all cull trees 1.0 inch d.b.h. and larger either cut or destroyed during logging operations and not used. These represent 69 percent of the total, or 14.6 tons per acre. In combination, these residues represent another 10.5 million tons of energy wood available yearly in Georgia. It should be noted that these weights do not include those residues available from stands experiencing cultural practices other than harvests.

Based on these assumptions, at least 28.0 million tons of energy wood could be harvested annually over the next 20 years, in harmony with conventional forestry practices and opportunities, without adversely affecting timber supplies. To put this quantity of wood in perspective, the total roundwood output for 1981 in Georgia was 39.6 million tons. The 28 million tons of available energy wood is about 70 percent of the total harvest of industrial products.

Table 9.--Area of noncommercial forest land, by forest types, Georgia, 1982

Type	All areas	Productive reserved areas	Unproductive areas
	- - - - - - - - - - - -	Acres	- - - - - - - - - - - -
Longleaf-slash pine	132,514	132,514	—
Loblolly-shortleaf pine	44,297	44,297	—
Oak-pine	2,293	2,293	—
Oak-hickory	90,357	90,048	309
Oak-gum-cypress	236,076	218,224	17,852
Elm-ash-cottonwood	3,217	3,217	—
	508,754	490,593	18,161

BIOMASS ON NONCOMMERCIAL LAND

Georgia's 0.5 million acres of noncommercial forest land support about 42 million tons of wood and bark of trees 1.0 inch d.b.h. and larger. More than 96 percent of the noncommerical forest is productive-reserved lands, the remaining 4 percent is unproductive. For analysis purposes, these areas have been further classified by forest type. More than 46 percent of the noncommercial forest land in Georgia is in oak-gum-cypress types. Another 36 percent is in yellow pine types, mostly longleaf-slash (table 9).

On productive-reserved land, the 218,000 acres of oak-gum-cypress stands account for nearly one-half of the wood and bark biomass (fig. 12). Yellow pine types account for one-third of the biomass, while oak-hickory stands make up 18 percent of both the acreage and biomass.

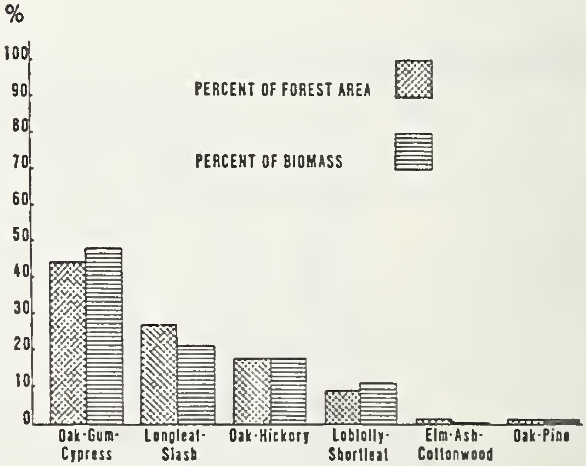

Figure 12.--Percent of distribution of the area and associated green weight of forest biomass o reserved forest land, by forest type, Georgia, 1982.

Table 10.--Green weight and volume of forest biomass per acre of noncommercial forest land, by forest type, Georgia, 1982

Forest type	All lands	Productive reserved	Unproductive	All lands	Productive reserved	Unproductive
	Tons per acre			Cubic feet per acre		
Longleaf-slash pine	63.9	63.9	—	1,708	1,708	—
Loblolly-shortleaf pine	107.5	107.5	—	2,893	2,893	—
Oak-pine	61.7	61.7	—	1,540	1,540	—
Oak-hickory	84.2	84.5	0*	2,153	2,160	0*
Oak-gum-cypress	84.6	91.1	4.8	2,282	2,459	123
Elm-Ash-Cottonwood	165.4	165.4	—	4,380	4,380	—
All types	81.5	84.4	4.7	2,173	2,249	119

*Sample too small to provide a reliable estimate.

On productive-reserved land, woody biomass averages 84.4 tons per acre (table 10). By forest type, the average green weight per acre ranges from a low of 61.7 tons in oak-pine stands to a high of 165.4 tons in elm-ash-cottonwood stands.

On unproductive forest land, the weight of woody biomass averages 4.7 tons per acre. Oak-gum-cypress stands make up more than 98 percent of the unproductive land and average 4.8 tons per acre. Many of these stands are stagnated blackgum ponds which are overstocked with poorly formed trees less than 1.0 inch d.b.h.

Weight per acre in unproductive oak-hickory types is insignificant, as most of these stands are found on poor coastal sites and consist of low-lying, poor-quality oaks and brush.

BIOMASS ON NONFOREST LAND

In many cases, the biomass associated with nonforest land takes on the appearance of forest land but does not qualify because of size or configuration. Examples are strips or stringers along streams, highway medians, or canals; riparian zones; isolated remnants of forest land less than 1 acre in pastures and fields; orchards; and group of trees in urban locations such as city parks. In each of these cases, the woody biomass in these "near forest" conditions has been associated with the nonforest land use in closest proximity.

To aid in the stratification of biomass on nonforest lands, a crown closure code, which reflects the stocking of trees 1.0 inch d.b.h. and larger on the sample acre, was assigned to each plot. A crown closure of 0 would indicate no biomass. In the field, 10 percent crown closure classes are recognized. For analysis, three classes were developed: 1-29 percent, 30-59 percent, and 60+ percent.

Area of Nonforest Land and Associated Biomass by Land Use

About 48 percent of Georgia's 12.9 million acres of forest biomass is cropland, 19 percent is improved pasture, 19 percent is urban and other, 6 percent is marsh and water, 5 percent is idle farmland, and 3 percent is other farmland (table 11). These areas collectively support about 46 million tons of woody biomass.

Table 11.--Area of nonforest land, by nonforest land use and percent crown closure class, Georgia, 1982

Nonforest use	Percent crown closure class				
	All classes	0	1-29	30-59	60+
	Acres				
Cropland	6,143,625	5,059,196	861,714	131,061	91,654
Pasture	2,505,404	1,594,328	770,876	114,679	25,521
Idle farmland	629,938	245,748	331,613	52,577	—
Other farmland	384,635	84,255	195,222	98,802	6,356
Urban	2,502,197	1,006,920	891,999	435,908	166,370
Marsh	428,226	401,440	16,072	—	10,714
Water	331,250	285,354	28,896	16,000	—
All uses	12,925,275	8,678,241	3,096,392	850,027	300,615

Table 12.--Per acre green weight of aboveground biomass associated with nonforest land, by land use and percent crown closure class, Georgia, 1982

Nonforest use	Percent crown closure class: All classes	0	1-29	30-59	60+
	- - - - - - - -	- - Tons per acre	- - - - - -	- - - - - -	- - - - -
Cropland	1.6	0	5.0	13.8	39.3
Pasture	3.4	0	5.7	28.1	35.7
Idle farmland	2.0	0	2.6	8.1	—
Other farmland	7.5	0	4.9	17.4	30.1
Urban	8.8	0	7.1	19.2	42.7
Marsh	2.1	0	1.8	—	79.5
Water	1.8	0	10.8	17.9	—
All uses	3.6	0	5.6	18.7	42.2

For these nonforest areas, the woody biomass averages about 3.6 tons per acre. Across all land uses, by crown closure class, average weight of woody biomass ranges from 5.6 tons per acre for nonforest sample plots assigned crown closures of 1-29 percent to 42.2 tons per acre for samples with crown closures greater than 60 percent (table 12).

By land use, the highest weight per acre was on urban lands, where woody biomass averages 8.8 tons per acre. Cropland and water had the lowest averages, with 1.6 and 1.8 tons per acre, respectively.

Biomass on Nonforest Land by Land Use and Species Group

Table 13 shows the distribution of woody biomass by land use and selected species groups. Yellow pine is the leading species in terms of total biomass, followed closely by the oaks. Combined, yellow pine and oak species account for about two-thirds of the total biomass. By land use, urban and other uses support the largest amount of biomass with 48 percent of the total. Cropland supports 21 percent; improved pasture, 19 percent; and other farmland, 6 percent. The remaining 6 percent is distributed among idle farmland, marsh, and water.

CONCLUSIONS

Georgia's 37.2 million acres of land area supports 1.8 billion tons of woody biomass. Commercial forest lands support 1.7 billion tons of biomass, or an average of 70.2 tons per acre; noncommercial forest lands support 42 million tons, or an average of more than 81 tons per acre; and nonforest lands support about 46 million tons, or an average of 3.6 tons per acre.

On commercial forest land, the total woody biomass on a per acre basis exceeds the green weight of conventional growing stock by 50 percent. Conventional growing stock accumulates somewhat faster in pine stands, especially in pine plantations, than in oak-pine and hardwood stands. By broad management class across all age classes, average weight of conventional growing stock ranged from a low of 25.4 tons per acre in pine plantations to a high of 61.8 tons per acre in lowland hardwood stands.

Since 1972, about 499,000 acres of timberland have been harvested annually in Georgia. Woody biomass left in standing trees after harvest averaged approximately 23 tons per acre. Total residues averaged about 21 tons per acre.

As of 1982, about 4.0 million acres of commercial forest were too poorly stocked with acceptable trees for timber production. These acres support an average of 29 tons per acre of woody biomass made up mostly of rough, rotten, and other low-quality trees. Most of this biomass could be removed and used for energy without adversely affecting prospective timber supplies.

These findings suggest at least 28 million tons of woody biomass could be harvested annually from commercial forest land in Georgia over the next 2 decades without adversely affecting timber

Table 13.--Total green weight of aboveground biomass on nonforest lands, by land use and species group, Georgia, 1982

Land use	All classes	Yellow pine	Other softwoods	Soft hardwoods	Oaks	Other hard hardwoods	Noncommercial
	- - - - - -	- - - - - -	- - - - - -	- - Tons	- - - - - -	- - - - - -	- - - - - -
Cropland	9,756,168	2,325,596	17,476	2,194,735	1,696,987	3,278,174	243,200
Pasture	8,579,930	2,656,016	205,926	1,135,957	3,825,584	501,788	254,659
Idle farmland	1,254,146	335,893	12,442	141,507	345,152	305,748	113,404
Other farmland	2,874,934	560,025	11,172	164,555	1,034,149	975,834	129,199
Urban	21,975,166	9,897,518	313,335	2,309,934	7,890,695	1,146,294	417,390
Marsh	880,880	1,001	814,402	62,714	0	0	2,763
Water	600,441	88,852	168,267	99,366	114,075	126,154	3,727
All uses	45,921,665	15,864,901	1,543,020	6,108,768	14,906,642	6,333,992	1,164,342

supplies. The green weight of this energy wood is about two-thirds of the total green weight of harvest of industrial roundwood in Georgia in 1981.

Noncommercial forest land makes up 1 percent of the land area in Georgia and supports 42 million tons of woody biomass, or an average of 81 tons per acre. More than 96 percent of the noncommercial forest land is classified as productive-reserved. Oak-gum-cypress is the leading forest type and accounts for about one-half of the biomass. By forest type, the average weight per acre ranged from a low of 61.7 tons for oak-pine stands to a high of 165.4 tons for elm-ash-cottonwood.

Of the 12.9 million acres of nonforest land in Georgia, about one-third supports woody biomass. For nonforest uses, the average weight of woody biomass per acre ranges from 5.6 to 42.2 tons when sample plots are stratified by crown closure. Yellow pine is the leading species in terms of total biomass. By land use, urban and other supports the largest amount of total biomass.

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USE OF SEGMENTED LOG-LOG EQUATIONS TO ESTIMATE TREE BIOMASS[1]

Alexander Clark III,[2] H. David Muse,[2]

Douglas R. Phillips,[3] and Douglas J. Frederick[4]

Abstract.--Five models that use d.b.h. and total height as independent variables are evaluated for estimating total tree and total stem green weights of Coastal Plain soft hardwoods and hard hardwoods. The models examined are linear, weighted linear, log-log, segmented log-log, and segmented linear. No single model was the best for all species and tree components. The segmented log-log model was selected as the final model for estimating hardwod biomass because of its overall application.

INTRODUCTION

Information on the weight, volume, and physical properties of hardwoods growing in the Gulf and Atlantic Coastal Plains is needed to improve utilization of tree products and for forest management planning. To meet these needs a southwide study was conducted by the North Carolina State Hardwood Research Cooperative and USDA Forest Service, Southeastern Forest Experiment Station, to quantify the biomass, nutrient, and energy content and distribution of hardwood trees and stands growing in the South. One objective of this study was to develop equations for predicting the weight and volume of individual trees and tree products. The Coastal Plain portion of this regional study has been completed and reported.[5] The report contains total-tree and tree-product green volume and green and dry weight equations for 10 hardwood species and the combined hard hardwoods and soft hardwoods.

This paper presents the prediction models examined for estimating total-tree and tree-product weight and volume and the criteria used for selecting the estimation models.

PROCEDURE

Tree weight and volume data used for development of species and species group equations were collected on 25 1/10-acre circular plots located in mixed, even-aged hardwood stands on the Gulf and Atlantic Coastal Plains. Four age classes (10, 20, 40, and 60 years) were sampled on three site types:

Bottom land. Floodplain of a major drainage system in which drainage is fairly rapid and the soils are loam to silt loam.

Swamp. Broad interstream areas characterized by very poor drainage with silt loam to clay soil that contains large amounts of raw organic material.

Wet flat. Broad interstream areas in which drainage is intermediate between bottom lands and swamps and the soils are nonalluvial and contain some organic matter accumulation.

All age and site combinations were replicated twice except the 40-year-old bottom-land site, which was replicated three times. The tree data collected on the 10-year-old plots were not used to develop species equations for trees 1.0 to 20.0 inches because of the differences in stem to crown proportions of these young, open-grown trees. Plots were randomly located within representative fully stocked stands. Location of the plots where trees were sampled for development of species equations are shown in figure 1. Also shown is the location of supplemental plots where additional trees were sampled for species not sampled sufficiently in the area plots for equation development.

1/ Paper presented at Sixth Annual Southern Forest Biomass Workshop, Athens, Georgia, June 5-7, 1984.

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5/ Clark, Alexander III; Phillips, Douglas R.; Frederick, Douglas J. Weight, volume, and physical properties of major hardwood species in the Gulf and Atlantic Coastal Plains. [In process.]

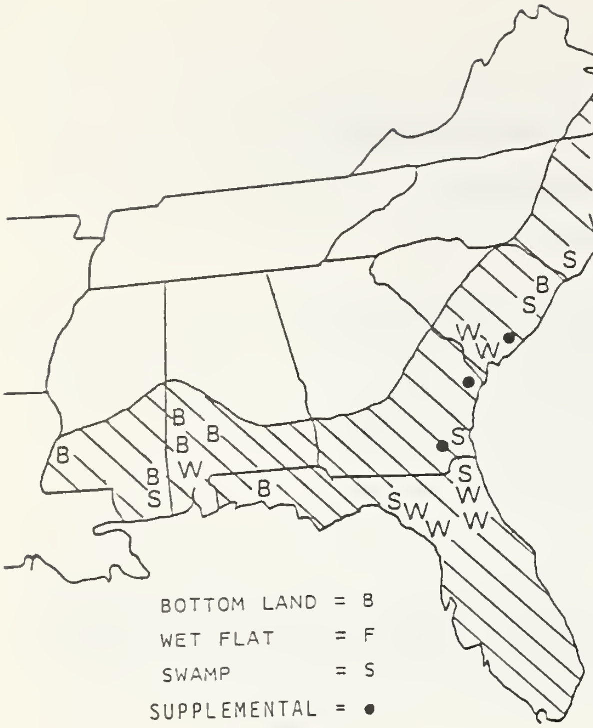

Figure 1.--Location of plots where trees were sampled for development of species equations.

All trees $\geq$ 5.0 inches d.b.h. on the 1/10-acre plots were sampled. At the center of each plot a concentric 1/50-acre plot was located on which all trees 1.0 to 4.9 inches d.b.h. were sample. At the supplemental locations, a stratified random sampled of three trees per 2-inch d.b.h. class was taken for commercially important species requiring additional sample trees for equation development.

Each tree was felled and measured for diameter outside bark (d.o.b.) at 4-foot intervals up the stem. Total height, and height to the saw-log top, 9-inch, 4-inch, 2-inch d.o.b., and base of full live crown were also recorded. Cross-sectional disks of wood and bark were removed from the stem and branches of each tree for laboratory determination of specific gravity, moisture content, bark percent, energy value, and nutrient concentration.

The weight of each tree was recorded by component (stem to a saw-log top, 9 to 4 inches, 4 to 2 inches, and 2 inches to tip and branches) to the nearest pound. The weight of wood only was estimated for each component by using the weighted average bark percent from the cross-sectional disks cut from each component. Green weights were converted to dry weights by using the component cross-sectional disks weighted average moisture content.

In this paper the soft hardwoods (species with excurrent crowns and average wood specific gravities below 0.54) and the hard hardwoods (species with deliquescent crowns and average wood specific gravities above 0.54) will be used as examples for selecting a prediction model.

Listed below are the major species sampled in each species group and the number of trees sampled.

Soft hardwoods		Hard hardwoods	
Species	No. trees sampled	Species	No. trees sampled
Green ash	158	Hickory	42
Blackgum	135	Laurel oak	47
Red maple	85	Water oak	112
Sweetgum	313	White oak	38
Water tupelo	79	Other species	64
Yellow-poplar	26		
Other species	46		
Total trees sampled	842		303

The soft hardwoods sampled averaged 7.1 inches d.b.h. and the hard hardwoods averaged 7.6 inches d.b.h.

Analysis

Regression equations were developed to predict green and dry weight and green volume of wood and bark in the total tree above stump, stem from butt to tip and to saw-log stem top. Independent variables were: diameter at breast height (D), total height (Th), saw-log merchantable height (Mh), and height to a 4-inch d.o.b. top (H4). In this paper the green weight of wood and bark equations based on d.b.h. and total height will be used to illustrate the predictability of the models evaluated.

Five models were evaluated for estimating total-tree and total-stem biomass--linear, weighted linear, log-log, segmented log-log, and segmented linear. The linear model was the simple linear model:

$$Y = a + b\,(D^2Th) + \varepsilon \qquad (1)$$

where:
- Y = predicted component weight or volume
- D = tree diameter at breast height in inches
- Th = tree total height in feet
- ε = experimental error
- a,b = regression coefficients

Since plots of the variance of total-tree and total-stem weights over D^2Th increased with increasing D^2Th, the weighted linear model was also tested:

$$\frac{Y}{(D^2Th)^K} = \frac{a}{(D^2Th)^K} \quad b(D^2Th)^{(D^2Th)^K} + \varepsilon \qquad (2)$$

where:
- K = weighting factor

The weighting factor (K) was computed by the procedure reported by McClure et al. (1983). The soft hardwood and hard hardwood trees were divided into equal D^2Th classes and the variance (V) of total-tree and total-stem weight computed for each class. The least squares model $l_n V = a + K l_n (D^2Th)$ was solved to obtain K. The value of K obtained for the total tree was 1.38 for soft hardwoods and 1.48 for hard hardwoods. For the total stem, K equaled 1.89 for the soft hardwoods and 1.02 for the hard hardwoods.

A logarithmic transformation (base 10) was also used to obtain a relatively homogeneous variance and the log-log model examined:

$$\text{Log}Y = a + b\ \text{Log}\ (D^2Th) + \varepsilon \qquad (3)$$

A segmented log-log model consisting of two equations--one for trees < 11.0 inches d.b.h. and one for trees $\geq$ 11.0 inches d.b.h.--was also tested. The 11-inch point was not the optimum point to shift from one equation to the other for all species or tree components but it was the most desirable from a practical standpoint. Hardwood trees < 11.0 inches in diameter are classified as sapling or poletimber and trees $\geq$ 11.0 inches are classified as sawtimber. The procedure outlined in Draper and Smith (1981) for fitting two linear equations with known point of intersection was used to develop the following equation for trees < 11.0 inches d.b.h.:

$$\text{Log}\ Y_p = a + b\ \text{Log}\ D^2Th + \varepsilon \qquad (4)$$

and the following equation for trees $\geq$ 11.0 inches d.b.h.:

$$\text{Log}\ Y_s = a + b\ \text{Log}\ (11^2Th) + c\ \text{Log}\ (D^2/11^2) + \varepsilon \qquad (5)$$

The segmented linear model:

$$Y = a + b\ (D^2Th) \qquad (6)$$

for trees < 11.0 inches d.b.h. and

$$Y = a + b\ (D^2Th) + c\ (Th) \qquad (7)$$

for trees $\geq$ 11.0 inches d.b.h. was also evaluated.

When logarithmic estimates are converted back to original units, they are biased downward because the antilogarithm of an estimated mean gives the geometric rather than the arithmetic mean (Cunia 1964). To adjust for this bias, the correction factor

$$\frac{(S^2_{y.x}\ \log_e 10)}{2}$$

where:

$S^2_{y.x}$ = error mean square form regression analysis

was computed and applied to each log-log model (Baskerville 1972).

The following exponential ratio equation was used to estimate the proportion of predicted total-stem weight or volume to a specified top d.o.b.:

$$Y_R = e^{a(d^b)(D^c)} \qquad (8)$$

where:

Y_R = predicted stem top d.o.b./total-stem ratio
d = specified stem top diameter in inches
D = tree diameter at breast height in inches
a,b,c = regression coefficients
e = base of natural log = 2.71828

The criteria commonly used for selecting a prediction model are the coefficients of determination (R^2) and the standard errors ($S_{y.x}$). The R^2 for the five models tested are:

Model	Coefficient of determination (R^2) Total tree	Total stem
	Soft Hardwoods	
Linear	0.94	0.95
Wt linear	.96	.96
Log-log	.99	.99
Seg log-log	.99	.99
Seg-linear	.95	.96
	Hard Hardwoods	
Linear	.98	.98
Wt linear	.98	.99
Log-log	.99	.99
Seg log-log	.99	.99
Seg-linear	.98	.98

These coefficients of determination and their standard errors are not directly comparable because some were calculated on transformed data. Thus, the sum of the deviations, sum of deviations squared, and sum of absolute deviations were used as criteria for selecting a model. All predicted values were transformed back to original units for calculation of their deviations.

As a general guide, the objective was to select a model which gave logical estimates, was not biased, and produced average deviations within $\pm$ 5 percent for trees from 1 to 20 inches d.b.h.

RESULTS AND DISCUSSION

Plots of the predicted total-tree and total-stem green weights over d.b.h. showed that the linear model resulted in illogical estimates for small d.b.h. trees. The estimated stem weight was greater than the estimated weight of the total tree for trees < 5 inches for soft hardwoods and trees < 4 inches for hard hardwoods. Thus, the linear model was not acceptable. The plots also showed the segmented linear model as unacceptable because it yielded negative estimates for trees < 3 inches d.b.h. Thus, the log-log, segmented log-log, and weighted linear models were the only models that produced logical estimates.

The average observed total-tree green weight with bark and average percent deviation of predicted weight for the log-log, segmented log-log, and weighted linear models are shown in table 1 for the soft hardwoods and hard hardwoods by d.b.h. classes and for all classes combined. The log-log equation was biased in its estimate. It overestimated the weight of the trees < 10 inches and underestimated the weight of the trees ≥ 12 inches for soft hardwoods and hard hardwoods. The weighted linear model was better than the log-log model but it also tended to underestimate the weight of the larger soft hardwoods. The segmented log-log model produced acceptable estimates of total-tree weights for the soft hardwoods across all size classes. Both the weighted linear and segmented log-log models yielded acceptable estimates for the hard hardwoods.

Table 1.--Observed total-tree weight and average percent deviation of predicted weight for the log-log, segmented log-log, and weighted linear models for soft hardwood and hard hardwood by d.b.h. classes

D.b.h. class (inches)	Sample size	Average observed weight	Average deviation		
			Log-log	Seg log-log	Wt. linear
	Number	Pounds	Percent		
		SOFT HARDWOODS			
2	199	18	0	2	-7
4	77	103	11	8	0
6	199	309	5	1	0
8	125	604	6	0	5
10	72	1040	6	-2	8
12	52	1734	-2	-5	3
14	48	2489	-6	0	1
16	38	3642	-14	-1	-5
18	22	4765	-19	-1	-10
20	10	5811	-13	11	-2
All classes	842	872	-6	0	-1
		HARD HARDWOODS			
2	87	19	5	5	-3
4	21	145	6	3	-6
6	53	364	9	4	1
8	26	782	5	1	1
10	27	1340	3	4	3
12	25	2104	5	1	7
14	27	3135	-4	-2	0
16	21	4360	-10	-3	-5
18	12	5558	-7	6	0
20	4	7616	-9	8	0
All classes	303	1342	-3	1	0

Table 2 shows the observed total stem weight and average percent deviation of predicted weight for the log-log, segmented log-log, and weighted linear models by d.b.h. class. As occurred when estimating the total tree, the log-log equation overestimated the stem of soft hardwood trees < 10 inches d.b.h. and underestimated the stem of trees $\geq$ 12 inches. The weighted linear model tended to underestimate the stem weight of the small trees and overestimated the weight of the larger soft hardwoods. The segmented log-log model produced acceptable estimates across all d.b.h. classes for the soft hardwoods. For the hard hardwoods all three models appear acceptable with the log-log and segmented log-log producing smaller more uniformly distributed residuals.

Exponential ratio equations (8) were developed for the soft and hard hardwoods and used to estimate the proportion of total stem estimated weight in the stem to a 4-inch top. As indicated by the average deviations in tables 2 and 3, the exponential ratio equation did a good job estimating the proportion of stem weight in the stem to a 4-inch top. The overall average residual increased by 1 percent or less when estimating stem weight to a 4-inch top from estimated total stem for the the three models tested.

Table 2.--Observed total stem weight and average percent deviation of predicted weight for the log-log, segmented log-log, and weighted linear models for soft hardwood and hard hardwood by d.b.h. classes

D.b.h. class (inches)	Sample size	Average observed weight	Average deviation		
			Log-log	Seg log-log	Wt. linear
	Number	Pounds	Percent		
			SOFT HARDWOODS		
2	199	12	0	1	-9
4	77	94	11	6	-2
6	199	280	5	-1	-2
8	125	545	6	0	3
10	72	913	6	2	9
12	52	1532	-2	-4	4
14	48	2092	-6	1	7
16	38	2987	-14	-1	3
18	22	3820	-19	-2	0
20	10	4663	-13	7	8
All classes	842	741	-3	0	4
			HARD HARDWOODS		
2	87	15	4	4	-1
4	21	119	2	1	-13
6	53	232	6	5	-4
8	26	655	-3	-5	-9
10	27	1094	-2	-4	-5
12	25	1628	4	3	5
14	27	2408	-4	-3	-2
16	21	3143	-4	1	0
18	12	4020	-1	4	4
20	4	5392	-1	5	7
All classes	303	1014	-1	0	0

Tables 4 and 5 show the average squared deviations and the sum of the absolute deviations, respectively, for the total tree and total stem of the soft hardwoods and hard hardwoods estimated by the log-log, segmented log-log, and weighted linear models. The average squared deviations and sum of the absolute deviations both indicate that the segmented log-log model is the most acceptable model for soft hardwoods. However, no one model was most acceptable for the hard hardwoods. There was little difference in the three models when applied to the hard hardwoods. The weighted linear and segmented log-log were good estimators of total tree weight, and all three models appear acceptable for estimating total-stem weight.

Table 3.--Observed stem weight to 4-inch top and average percent deviation of predicted weight for the log-log, segmented log-log, and weighted linear models for soft hardwoods and hard hardwoods by d.b.h. classes

D.b.h. class (inches)	Sample size	Average observed weight	Average deviation		
			Log-log	Seg log-log	Wt. linear
	Number	Pounds	Percent		
		SOFT HARDWOODS			
6	199	208	0	-2	-4
8	125	545	4	1	4
10	72	873	6	3	11
12	52	1532	-2	-4	5
14	48	2059	1	2	8
16	38	2955	-7	-1	3
18	22	3785	-11	-2	0
20	10	4622	-5	8	10
All classes	566	1032	-3	0	5
		HARD HARDWOODS			
6	53	231	4	2	-7
8	26	608	-2	-4	-8
10	27	1053	0	-3	-3
12	25	1591	6	5	6
14	27	2370	-2	-2	-1
16	21	3108	-3	0	1
18	12	3987	-1	4	5
20	4	5354	-1	6	7
All classes	195	1511	-1	1	1

Table 4.--Comparison of the average squared deviations for the total tree and total stem for the soft hardwoods and hard hardwoods estimated using the log-log, segmented log-log and weighted linear models

Model	Average squared deviations	
	Total tree	Total stem
	SOFT HARDWOODS	
Log-log	130,800	67,332
Segmented log-log	93,048	59,867
Weighted linear	97,635	62,167
	HARD HARDWOODS	
Log-log	102,210	25,329
Segmented log-log	79,588	25,744
Weighted linear	77,776	27,175

Table 5.--Comparison of the sum of the absolute deviation for the total tree, and total stem, and stem to 4-inch top for the soft hardwoods and hard hardwoods estimated using the log-log, segmented log-log, and weighted linear models

Model	Sum of absolute deviations	
	Total tree	Total stem
	SOFT HARDWOODS	
Log-log	135,238	101,930
Segmented log-log	116,735	94,833
Weighted linear	120,585	95,391
	HARD HARDWOODS	
Log-log	45,879	25,176
Segmented log-log	43,876	25,200
Weighted linear	43,280	26,358

SUMMARY

Five models--a linear, weighted linear, log-log, segmented log-log, and segmented linear--using d.b.h. and total height as independent variables were evaluated for estimating total-tree and total-stem weight of hardwood trees 1 to 20 inches d.b.h. No one model was the most acceptable for all species and tree components. The linear and segmented linear models were unacceptable because they produced impractical estimates for trees < 5 inches d.b.h. The segmented linear model, however, appears to be an acceptable model for estimating the biomass of trees ≥ 5 inches using d.b.h. and height to a 4-inch top. The log-log model overestimated the weight of trees ≤ 10 inches and underestimated the weight of trees > 10 inches for both the soft and hard hardwoods and thus was unacceptable. The weighted linear model was also biased when applied to the soft hardwoods and for estimating the stem of hard hardwoods but gave acceptable estimates for the total tree of hard hardwoods. The segmented log-log model was the most acceptable model for estimating the total tree and total stem of soft hardwoods and acceptable for the hard hardwoods, thus it was selected as the final model for estimating hardwood biomass.

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TIMBER RESOURCE ESTIMATES USING THE TOTAL-TREE MULTIPRODUCT CRUISE PROGRAM[1/]

by

Thomas M. Burgan[2/] and Alexander Clark III[3/]

Abstract.--The Total-Tree Multiproduct Cruise Program is an interactive computer program used to estimate the weight and volume of forest products in timber stands. Products estimated are saw logs, plylogs, chipping logs, pulpwood, and fuelwood. Weight and volume equations, developed from biomass data collected across the South, are stored in the program for commercially important tree species. Given data from a standard timber cruise, the program produces tables detailing the biomass of the total tree and its products. Weight estimates are given in tons, and volume estimates are given in cunits, cords, or board feet. The output tables can be printed on a per-acre or per-stand basis, or as tract total. Projected weight and volume estimates for up to 5 years are also available. Two versions of the Total-Tree Multiproduct Cruise Program have been developed. One version is written in FORTRAN and is available for operation on mainframe computers. A second version is being written in PASCAL for use with microcomputers.

INTRODUCTION

Interest in wood as an alternate fuel and changing timber harvesting practices have created a need for estimating the total product mix in forest stands. The Total-Tree Multiproduct (TTMP) Cruise Program meets this need. It is an interactive program which estimates the green weight and volume of the total tree and its products in a timber stand. These products include saw logs, plylogs, chipping logs, pulpwood, crown firewood, and logging residues.

The TTMP Cruise Program was developed by the USDA Forest Service, Southeastern Forest Experiment Station, Athens, Georgia, in cooperation with the Georgia Forestry Commission and the University of Georgia School of Forest Resources. The weight and volume equations used in the program were derived from biomass data collected across the South by the Utilization of Southern Timber Research Unit in cooperation with forest industries, Region 8 of the USDA Forest Service, the North Carolina State Hardwood Research Cooperative, the Georgia Forestry Commission, and the Tennessee Valley Authority. These equations represent the commercially important species or species groups in each of the three main physiographic regions in the South--the Gulf and Atlantic Coastal Plains, Piedmont, and the Southern Appalachian Mountains.

The first version of the TTMP Cruise Program was designed for operation on a mainframe computer (Clark and Field 1981, Clark et al. 1984). It is written in FORTRAN V, and is currently running on both the Cyber 750 and the IBM 370 systems at the University of Georgia. The use of standard language syntax simplifies the conversion of this program for running on other systems supporting FORTRAN V. Accessing the program from remote terminals, the Georgia Forestry Commission has used the TTMP Cruise Program for more than 3 years for timber sales and forest management assistance to landowners. Other states, industries, consultants, and the USDA Forest Service are using the program as it is made available. With the recent developments in personal computing hardware and software, the design of a microcomputer version of the TTMP Cruise Program was a logical step toward expanding its accessibility and use.

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The microcomputer version is written in PASCAL for use on IBM personal computers. This program requires two disk drives and a minimum of 256K RAM storage. Since it is a program requiring much user interaction, the TTMP Cruise Program uses a microcomputer's interactive environment and utilities to its advantage. All input screens are self-explanatory and require little prior knowledge of the program. Data can be quickly entered and edited. Special features are included in the microcomputer version which help minimize the number of user key strokes per run. Spending less time at the keyboard lessens the chance of user input errors.

PROGRAM DESIGN

The TTMP Cruise Program is a versatile program that allows foresters to use tree cruise data collected by their normal cruise procedures and to obtain estimates of not only conventional forest products but total tree and residual biomass for energy. The program will accept cruise data from fixed-area plots, point sampling (prism) plots, strip, or 100 percent mark cruise tallies. For each stand cruised on a tract, cruise tallies are entered by tree size class (saplings, pulpwood, and sawtimber) for each species tallied within that stand. These cruise tallies consist of cumulative tree counts by d.b.h. class alone or by d.b.h. class and height class.

TTMP will accommodate trees 1 to 30 inches d.b.h. and 10 to 140 feet in height. Tree counts are entered either by 1- or 2-inch d.b.h. classes. Height of trees tallied by total height or height to a 4-inch top are entered in 5- or 10-foot intervals. Trees in the sawtimber size class may also be tallied by saw-log merchantable height in half-log intervals. The user is asked to identify the tree dimensions recorded for each tree size class tallied for a species. The program will accept the cruise data for a maximum of six species or species groups for each stand or a maximum of nine species over the entire tract.

The weight and volume estimates for the tree species tallied in a cruise are calculated by region-specific equations. These equations provide estimates of the green weight of wood and bark and the volume of wood in the total tree above the stump and in the stem from butt to tip. The equations were derived from allometric models using d.b.h. only, d.b.h. and total height, d.b.h. and height to a 4-inch top, or d.b.h. and merchantable height as the independent variable. Ratio models were developed for estimating the proportion of the stem weight or volume to any specified pulpwood top d.o.b. This allows for more accurate estimates of weight and volume of all products.

The program gives the user several additional options. It allows the user to specify a different cruise procedure for tallying sapling trees. Due to the lower market value of this material, foresters may wish to cruise sapling trees at a lower intensity than for pulpwood and sawtimber trees. When natural pine stands are cruised, the user has the option of separating the saw-log merchantable stem estimate into plylogs and small saw logs. The program will prompt the user for the minimum tree d.b.h. from which plylogs can be marketed and the minimum top d.o.b. to which plylogs can be bucked. When plantation pine stands are cruised, the user has the option of having the weight and volume of chipping-saw material estimated for a stand. Again, the user will be prompted for both a minimum d.b.h. and a minimum top d.o.b. for defining a tree in this product group.

If desired, estimates in cords can be calculated from the estimated weight of wood and bark. Pounds per cord equivalents are stored in the program by region for each of the three major species groups--pine and other softwoods, hard hardwoods, and soft hardwoods. The user has the option of specifying pounds-per-cord ratios different from those stored in the program.

As indicated earlier, the program can, if desired, provide projected yields for up to 5 years. Growth projections are made by using a stand table projection procedure designed by the Forest Inventory and Analysis Work Unit, Southeastern Forest Experiment Station, USDA Forest Service.[4/] Diameter growth predictions are calculated from average annual radial growth values. Radial growth increments are estimated from core measurement data collected by the user or from equations developed from forest inventory data collected in the Southeast by the USDA Forest Service. These average annual radial increment equations and projected heights are stored in the program by physiographic region for pine, other softwoods, soft hardwood, and hard hardwood species groups.

PROGRAM OUTPUT

The program output shows the aggregate weight or volume of the total tree above stump for all trees in the stand by species or species groups. These estimates are further broken down into saw logs, pulpwood, and crown firewood by d.b.h. class. Weight is given in tons, and volume in cords, cunits, or board feet on a per-acre, per-stand, or entire tract basis. This information is provided in three basic output tables.

[4/] Personal communication with Joe P. McClure, Project Leader, Forest Inventory and Analysis, Asheville, NC, 1983.

Table 1.--Example of the table showing estimated Scribner board-foot volume for form class 78 by d.b.h. class

TOTAL TREE MULTI-PRODUCT CRUISE PROGRAM

LANDOWNER -	JOHN DOE	CASE NO. - 16A	
ADDRESS -	MAIN ST ATHENS GA 30602	DISTRICT NO. -	14
TRACT LOC.-	GREEN CO	TOTAL TRACT(AC) -	40.0
AREA 1 -	PINE-HARDWOOD	AREA 1 ACREAGE -	40.00
FORESTER -	SMITH	PHONE - 404-546-2441	
ADDRESS -	ATHENS GA	DATE - 84/09/06.	

DBH (IN.)	AVERAGE HEIGHT (LOGS)			EST. NO. OF TREES (NUMBER)			SAWLOG VOLUME-SCRIBNER,FC /1/ (THOUSAND BOARD FEET)			
	PINE	HHWD	SHWD	PINE	HHWD	SHWD	PINE	HHWD	SHWD	ALL SPECIES
10	1.7	0.0	0.0	21.1	0.0	0.0	0.8	0.0	0.0	0.8
12	1.9	1.5	2.0	16.2	1.6	2.5	1.2	0.1	0.2	1.4
14	1.7	1.8	2.4	6.5	3.7	5.1	0.7	0.4	0.7	1.7
16	2.2	2.0	2.5	5.6	0.7	0.7	0.9	0.1	0.1	1.2
18	2.3	2.0	0.0	1.0	0.3	0.0	0.2	0.1	0.0	0.3
20	2.3	0.0	0.0	1.1	0.0	0.0	0.3	0.0	0.0	0.3
ALL CLASSES				51.6	6.3	8.4	4.1	0.7	1.0	5.8

/1/ FORM CLASS: PINE= 78.; SOFT HWD= 78.; HARD HWD= 78.

Table 1 shows the predicted gross board-foot volumes by d.b.h. class. These estimates can be computed with Doyle, Scribner, or International 1/4-inch log rules. Board-foot volumes, as well as average saw-log heights and the estimated number of trees, are displayed for the species or species group tallied. An estimate of the total volume by d.b.h. classes and for all d.b.h. classes is also provided. Only those species having sawtimber trees tallied by d.b.h. and total height, d.b.h. and height to a 4-inch top, or d.b.h. and merchantable height are included in this table.

Table 2 gives the predicted weight of the total tree and its components (stem to pulp top, saw logs, pulpwood, and crown firewood $\geq$ 4 inches d.o.b. (hardwood only)) by d.b.h. class for each species. The estimates in table 2 can also be expressed in cords or cunits. In the case where chipping-saw output is desired, the estimated weight and volume of this product group would replace the saw-log estimates in the table.

Table 3A summarizes what was given in tables 1 and 2, and shows the predicted total biomass of all trees in the stand in tons, cords, and cunits for each species and all species combined. Estimated total biomass is displayed for sapling trees 1.0 to 4.9 inches and for trees $\geq$ 5.0 inches d.b.h. The biomass in trees $\geq$ 5.0 inches is divided into material in the stem to a pulpwood top and material in the crown (branches and stem above the pulp d.o.b. top). The stem to a pulpwood top is further separated into saw log and pulpwood components. The component consists of estimates of pulpwood in pulpwood size trees and the material from the tops of sawtimber size trees. If plylog output is desired, the saw-log estimate for natural pine will be separated into plylogs and small saw logs not meeting the peeler log requirements specified by the user. Table 3B summarizes, by species and over all species in an area, the saw-log board-foot volumes, and provides an estimate of the basal area and quadratic mean diameters by tree size class.

If growth projection is desired for a stand, future yields are shown in table 3A and table 3B. For some of the more conventional timber products, table 4 displays the present volume per acre, an estimate of the annual growth per acre, the total annual growth for the stand, and the estimated percent annual change in amount of wood material over the projection period. Annual growth is expressed in board feet for saw logs, in cords for pulpwood, and in tons for total-tree chips.

Table 2.--Example of the table showing estimated total-tree and tree-component biomass in tons by d.b.h. class

TOTAL TREE MULTI-PRODUCT CRUISE PROGRAM

LANDOWNER - JOHN DOE
ADDRESS - MAIN ST ATHENS GA 30602
TRACT LOC.- GREEN CO
AREA 1 - PINE-HARDWOOD
FORESTER - SMITH
ADDRESS - ATHENS GA

CASE NO. - 16A
DISTRICT NO. - 14
TOTAL TRACT(AC) - 40.0
AREA 1 ACREAGE - 40.00
PHONE - 404-546-2441
DATE - 84/09/06.

DBH	AVERAGE HEIGHT	EST. TREES	TOTAL TREE	STEM TO PULP TOP/1/	SAWLOGS	STEM PULPWOOD	FIREWOOD >= 4 IN.
(IN)	(FT.&LOGS)	(NO.)	----------	----------	TONS	----------	----------
				PINE			
				--SAPLINGS--			
2	0.0	68.8	0.5				
4	0.0	51.6	2.5				
				--PULPWOOD--			
6	23.0	34.4	4.4	3.0		3.0	
8	36.4	41.5	11.9	10.0		10.0	
				--PULPWOOD--			
12	43.3	1.0	0.7	0.6		0.6	0.0
16	50.0	0.4	0.5	0.4		0.4	0.0
				--SAWTIMBER--			
10	1.7	21.1	9.4	8.4	6.8	1.6	0.0
12	1.9	16.2	11.1	9.9	8.1	1.8	0.0
14	1.7	6.5	5.7	5.1	4.0	1.1	0.0
16	2.2	5.6	7.5	6.4	5.4	1.0	0.0
18	2.3	1.0	1.7	1.5	1.2	0.2	0.0
20	2.3	1.1	2.4	2.0	1.7	0.3	0.0
ALL CLASSES		249.1	58.2	47.4	27.2	20.2	0.0

/1/STEM PULPWOOD TOP:
PULPWOOD - 4-IN. FOR PINE; 4-IN. FOR HHWD; 4-IN. FOR SHWD.
SAWTIMBER - 4-IN. FOR PINE; 4-IN. FOR HHWD; 4-IN. FOR SHWD.

Table 3A.--Example of the table which summarizes the predicted total-tree and tree-component weights and volumes by species

TOTAL TREE MULTI-PRODUCT CRUISE PROGRAM

LANDOWNER -	JOHN DOE	CASE NO. - 16A	
ADDRESS -	MAIN ST ATHENS GA 30602	DISTRICT NO. -	14
TRACT LOC.-	GREEN CO	TOTAL TRACT(AC) -	40.0
AREA 1 -	PINE-HARDWOOD	AREA 1 ACREAGE -	40.00
FORESTER -	SMITH	PHONE - 404-546-2441	
ADDRESS -	ATHENS GA	DATE - 84/09/06.	

COMPONENT	PINE	HARD-HWD	SOFT-HWD	ALL TREES/3/
GREEN TONS OF WOOD AND BARK				
TOTAL TREE(ALL)	58.2	19.4	17.4	95.0
SAPLINGS(< 5 IN.)	3.1	3.1	2.9	9.1
TOTAL TREE(>= 5 IN.)	55.2	16.3	14.5	86.0
STEM TO PULPWOOD TOP/1/	47.4	11.6	11.8	70.8
ALL SAWLOGS/2/	27.2	5.2	6.9	39.3
SMALL SAWLOGS/5/	19.1	0.0	0.0	19.1
PLYLOGS/6/	8.2	0.0	0.0	8.2
PULPWOOD (ALL)	20.2	6.5	4.9	31.6
PULPWOOD TREES	14.1	4.5	3.1	21.7
SAWTIMBER TOPS	6.1	1.9	1.9	9.9
TOTAL CROWN	7.8	4.7	2.7	15.1
CROWN FIREWOOD>=4IN	0.0	0.8	0.3	1.1
CORDS OF WOOD AND BARK/4/				
TOTAL TREE(ALL)	21.8	6.8	6.1	34.7
SAPLINGS(< 5 IN.)	1.1	1.1	1.0	3.2
TOTAL TREE(>= 5 IN.)	20.6	5.7	5.1	31.4
STEM TO PULPWOOD TOP/1/	17.7	4.1	4.1	25.9
ALL SAWLOGS/2/	10.2	1.8	2.4	14.4
SMALL SAWLOGS/5/	7.1	0.0	0.0	7.1
PLYLOGS/6/	3.1	0.0	0.0	3.1
PULPWOOD (ALL)	7.5	2.3	1.7	11.5
PULPWOOD TREES	5.3	1.6	1.1	7.9
SAWTIMBER TOPS	2.3	0.7	0.7	3.6
TOTAL CROWN	2.9	1.6	0.9	5.5
CROWN FIREWOOD>4IN	0.0	0.3	0.1	0.4
VOLUME OF WOOD (CUNITS)				
TOTAL TREE(ALL)	16.7	4.8	4.9	26.4
SAPLINGS(< 5 IN.)	0.8	0.8	0.8	2.4
TOTAL TREE(>=5 IN.)	15.9	4.0	4.1	24.0
STEM TO PULPWOOD TOP/1/	13.6	3.0	3.4	20.0
ALL SAWLOGS/2/	7.9	1.3	2.0	11.2
SMALL SAWLOGS/5/	5.6	0.0	0.0	5.6
PLYLOGS/6/	2.3	0.0	0.0	2.3
PULPWOOD (ALL)	5.7	1.6	1.4	8.8
PULPWOOD TREES	4.2	1.2	0.9	6.2
SAWTIMBER TOPS	1.6	0.5	0.5	2.6
TOTAL CROWN	2.3	1.1	0.7	4.0
CROWN FIREWOOD>=4IN	0.0	0.2	0.1	0.3

/1/STEM PULPWOOD TOP:
PULPWOOD - 4-IN. FOR PINE; 4-IN. FOR HHWD; 4-IN. FOR SHWD.
SAWTIMBER - 4-IN. FOR PINE; 4-IN. FOR HHWD; 4-IN. FOR SHWD.

/2/SAWLOG MERCHANTABILITY: 7-IN. FOR PINE W/ MIN DBH 9-IN., 9-IN. FOR HARDWOODS OR THRU LOG GRADE NO. 3 MERCHANTABILITY W/ MIN DBH 11-IN.

/3/NUMBERS MAY NOT ADD DUE TO ROUNDING ERROR.

/4/POUNDS PER CORD: PINE=5350. HHWD=5700. SHWD=5700.

/5/SMALL SAWLOGS - MIN 8 FT. W/ MIN 5-IN. DOB SMALL END.

/6/PLYLOGS - MIN 2 8.7 FT. BLOCK W/ MIN 10.0-IN. DOB SMALL END, MIN DBH - 14.0.

Table 3B.--Example of the table which summarizes the predicted saw-log board-foot volumes, basal area per acre and mean d.b.h. by species

TOTAL TREE MULTI-PRODUCT CRUISE PROGRAM

LANDOWNER -	JOHN DOE	CASE NO. - 16A	
ADDRESS -	MAIN ST ATHENS GA 30602	DISTRICT NO. -	. 14
TRACT LOC.-	GREEN CO	TOTAL TRACT(AC) -	40.0
AREA 1 -	PINE-HARDWOOD	AREA 1 ACREAGE -	40.00
FORESTER -	SMITH	PHONE - 404-546-2441	
ADDRESS -	ATHENS GA	DATE - 84/09/06.	

COMPONENT	PINE	HARD-HWD	SOFT-HWD	ALL TREES
SAWLOG BOARD-FOOT VOLUME---(MBF)/1/				
ALL SAWLOGS				
DOYLE	2.6	0.4	0.6	3.7
SCRIBNER	4.1	0.7	1.0	5.8
SMALL SAWLOGS				
DOYLE	1.6	0.0	0.0	1.6
SCRIBNER	2.6	0.0	0.0	2.6
PLYLOGS				
DOYLE	1.1	0.0	0.0	1.1
SCRIBNER	1.5	0.0	0.0	1.5
BASAL AREA PER ACRE (SQ.FT.)				
SAPLINGS TREES	5	4	5	14
PULPWOOD TREES	22	6	5	33
SAWTIMBER TREES	43	6	8	57
ALL TREES	70	16	18	104
QUADRATIC MEAN D.B.H. (IN.)				
SAPLING TREES	3.0	3.2	2.6	2.9
PULPWOOD TREES	7.3	7.4	7.1	7.3
SAWTIMBER TREES	12.4	14.0	13.6	12.7
ALL TREES	7.3	5.6	4.6	6.2

/1/FORM CLASS: PINE= 78.; SOFT HWD= 78. HARD HWD= 78.

Table 4.--Example of the table which shows projected annual growth over 5 years by stand component

TOTAL TREE MULTI-PRODUCT CRUISE PROGRAM

LANDOWNER -	JOHN DOE	CASE NO. - 16A	
ADDRESS -	MAIN ST ATHENS GA 30602	DISTRICT NO. -	14
TRACT LOC.-	GREEN CO	TOTAL TRACT(AC) -	40.0
AREA 1 -	PINE-HARDWOOD	AREA 1 ACREAGE -	40.00
FORESTER -	SMITH	PHONE - 404-546-2441	
ADDRESS -	ATHENS GA	DATE - 84/09/06.	

STAND COMPONENT	PRESENT VOLUME PER ACRE	PRESENT GROWTH PER ACRE PER YEAR	TOTAL ANNUAL GROWTH PER AREA	PERCENT ANNUAL CHANGE PER ACRE
AREA 1-- 40.00 ACRES-PINE-HARDWOOD				
PINE				
ALL SAWLOGS (MBF SCRIB)	4.1	.245	9.82	5.96
SMALL SAWLOGS (MBF)/1/	2.6	.130	5.20	4.97
PLYLOGS (MBF)/2/	1.5	.115	4.62	7.69
STEM TO PULP TOP (CORDS)	17.7	.683	27.34	3.86
PULPWOOD (CORDS)	7.5	.135	5.42	1.80
TOTAL TREE CHIPS (TONS)	58.2	1.964	78.56	3.37
HARD-HWD				
ALL SAWLOGS (MBF DOYLE)	0.4	.018	0.71	3.98
STEM TO PULP TOP (CORDS)	4.1	.153	6.11	3.74
PULPWOOD (CORDS)	2.3	.108	4.31	4.73
TOTAL TREE CHIPS (TONS)	19.4	.584	23.35	3.00
SOFT-HWD				
ALL SAWLOGS (MBF DOYLE)	0.6	.035	1.39	5.54
STEM TO PULP TOP (CORDS)	4.1	.164	6.58	3.96
PULPWOOD (CORDS)	1.7	.076	3.03	4.38
TOTAL TREE CHIPS (TONS)	17.4	.550	22.01	3.17
ALL SPECIES				
ALL SAWLOGS (MBF)				
SAWLOGS (DOYLE)	1.1	.052	2.10	4.89
SAWLOGS (SCRIB)	4.1	.245	9.82	5.96
STEM TO PULP TOP (CORDS)	25.9	1.001	40.03	3.86
PULPWOOD (CORDS)	11.5	.319	12.75	2.76
TOTAL TREE CHIPS (TONS)	95.0	3.098	123.92	3.26

/1/SMALL SAWLOGS - MIN 8 FT. W/ MIN 7-IN. DOB SMALL END.

/2/PLYLOGS - MIN 2 8.7 FT. BLOCK W/ MIN 10.0-IN. DOB SMALL END,
MIN DBH - 14.0.

NOTE: NEGATIVE REFLECTS MOVEMENT OF MATERIAL INTO LARGER SIZE COMPONENT.
GROWTH ASSUMES APPROX. 1% ANNUAL MORTALITY.

SUMMARY

The Total-Tree Multiproduct (TTMP) Cruise Program provides useful information for marketing timber stands for their highest value. It can be an effective tool in providing the landowner and the forester with weight and volume estimates for not only conventional forest products, but also estimates for crown firewood and fuelwood chips. Accurate estimates of both conventional and other products are important when planning marketing strategies in a diverse market.

The FORTRAN V code for the TTMP Cruise Program for use on a mainframe computer, as well as information concerning the microcomputer version, is available upon request from the Southeastern Forest Experiment Station, Utilization of Southern Timber Research Work Unit, Athens, Georgia.

LITERATURE CITED

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SESSION II

Research Results, Biomass Characterization

Clifford Henry, Moderator

PRELIMINARY RESULTS FOR WEIGHT AND VOLUME OF EVEN-AGED, UNTHINNED, PLANTED SOUTHERN PINES ON THREE SITES IN LOUISIANA[1/]

MARK D. GIBSON, CHARLES W. McMILLIN, AND EUGENE SHOULDERS[2/]

Abstract.--Three uniform sites in Northern Louisiana (wet, intermediate, and dry) were selected from a 25-year growth and yield study of planted, unthinned southern pines. Complete tree green and dry weight and cubic volume were determined for twelve loblolly, longleaf, slash, and shortleaf pines grown to the same age on each site. Species were compared for weight and volume production on each site with analysis of variance techniques. The dry and intermediate sites showed no significant species differences at the 5% level. The wet site, however, exhibited highly significant species differences for all variables examined. Prediction equations to estimate complete tree dry weight, green weight, and cubic volume for each species on each site were developed using d.b.h. and total height as independent variables.

INTRODUCTION

Biomass studies of our four major southern pines, loblolly (*Pinus taeda* L.), longleaf (*Pinus palustris* Mill.), shortleaf (*Pinus echinata* Mill.), and slash (*Pinus elliottii* Engelm. var. *elliottii*), have not addressed directly differences between the species in total volume and weight of materials they produce in plantations under identical site conditions, planting densities and management practices. Clark and Taras (1976) compared aboveground biomass components for the four species in natural, closed, uneven-age sawtimber stands, but each species came from a different location. Edwards and McNab (1979) compared sapling-sized trees of the four species, but again all were not present on the same site. Cole, Zobel, and Roberds (1966) contrasted slash, loblolly, and longleaf pines from a mixed, natural, even-aged stand on a relatively uniform site, but only investigated species differences in volume and wood properties.

Site, geographic origin, age, and other variables certainly affect species differences. Therefore, removal of these effects from a comparison of species should provide a more accurate data base from which managers can make decisions regarding forest management practices and wood utilization strategies.

Considering these possible benefits, we set out to compare the aboveground and belowground weight and volume production of the four major species grown to the same age on the same site, and to develop prediction equations for the complete tree[3/] and its component parts.

This paper reports our preliminary findings on species differences and prediction equations for complete tree green weight, dry weight and cubic volume production.

FIELD METHODS

During the years 1954 to 1958, 113 installations were planted by the U.S. Forest Service, Southern Forest Experiment Station and their cooperators in public and private forestry organizations. These sites, scattered across Louisiana

1/Paper presented at Sixth Annual Southern Forest Biomass Workshop, Athens, Georgia, June 5-7, 1984.

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3/Complete tree in this paper refers to all wood and bark in the taproot, stem, and crown including both live and dead branches and foliage.

and Mississippi, were established as a comparative growth and yield study of the four major southern pines. Each installation was classified as wet, intermediate, or dry on the basis of soil characteristics. Stand characteristics were measured at 5-year intervals, and growth and yield data through age 20 were summarized and reported in Shoulders (1976, 1977, 1983), Shoulders and Walker (1979), and Shoulders and Tiarks (1980). Upon completion of the 25th year inventory, three distinct sites in Northern Louisiana were chosen for more detailed study of aboveground and belowground volumes and weights of the four species.

Each of our three locations represented a distinctly different soil type. The wet site in Winn Parish was a poorly-drained silt loam of the Caddo series. The intermediate site in Jackson Parish consisted of a well-drained sandy loam of the Shubuta series. The dry site, located in Bienville Parish, was an excessively deep sand of the Alaga series.

The sites consisted of 12 plots arranged in a randomized complete block design (three blocks with each of the four species represented in each block). On each species plot, the trees had been planted on a 6 x 6-foot spacing and left unthinned. Four trees were selected from each plot for a total of 12 trees of each species or 48 trees at each location. Trees were chosen using the 25th-year measurement data from each plot. D.b.h.'s were ranked; the ranking was divided into quarters; and the midpoint of each quarter and its corresponding tree number were taken as a sample tree. All trees selected in this manner were to be free from forking, excessive sweep, and atypical characteristics caused by disease or mechanical damage. If field examination indicated otherwise, trees adjacent to the original in the d.b.h. ranking were examined until these criteria were met.

ABOVEGROUND SAMPLING

Prior to felling, crown class of each tree was recorded and d.o.b. at 0.5-feet (stump height) and d.b.h. were measured. Trees were severed at the 0.5-foot level with a chainsaw and the length to base of live crown, length to a 4-inch d.o.b. top, length to a 2-inch d.o.b. top, and total length were determined. Means and ranges for d.b.h. and total height are presented in table 1. Branches were removed from the stem and segregated into four categories: all dead branches regardless of size, branches with d.o.b. $\geq$ 2-inches, branches with 0.25-inch $\leq$ d.o.b. $<$ 2-inches and branches with d.o.b. $<$ 0.25-inch including needles.

The main stem was bucked into 8.5-foot segments from the butt to a point just below the 4-inch d.o.b. top. From the remainder of the stem, three variable length segments were removed: a piece extending from the top of the last 8.5-foot segment to the 4-inch d.o.b. top, a piece extending from the 4-inch d.o.b. top to the 2-inch d.o.b. top, and a piece extending from the 2-inch d.o.b. top to the apical tip. The length (nearest 0.1-foot) and d.o.b. (nearest 0.1-inch) at top and bottom of each stem segment were measured. All components, stem and branch, were weighed separately in the field to the nearest ¼-pound on a 300-pound capacity platform scale. After weighing, a draw-knife was used to remove the bark at breast height and d.i.b. at b.h. was measured to the nearest 0.1-inch.

Disks for the determination of percent bark, moisture content, and specific gravity were removed from the base of each stem segment and from each branch category. Disks were marked, sealed in polyethylene bags, and stored in a cooler for later laboratory analysis.

BELOWGROUND SAMPLING

Following measurement, sampling, and removal of aboveground material on each site, the stump-taproot system was excavated with a tractor-mounted backhoe. Root systems were transported to the laboratory, washed with water to remove excess soil, and lateral roots extending beyond an 11-inch radius from the pith were severed. This radius is equivalent to the dimensions of the clamshell-hinged tubular shear on the Rome lateral root shear and tree puller (Koch 1980).

Stump-taproots were weighed to the nearest ¼-pound. Total length, length from base of major laterals to taproot tip, and d.o.b. at five positions along the stump-taproot system were measured. Means and ranges for maximum taproot d.o.b. and total stump-taproot length are presented in table 2.

Disks were removed at each diameter measurement point for determination of root wood and bark physical properties. Disks were sealed in polyethylene bags and stored in a cooler for later laboratory analysis.

LABORATORY METHODS

Sample disks from branches, stems, and stump-taproots were used to determine wood and bark physical properties. Bark percentage was determined by weighing each disk with and without bark. Specific gravity of wood and bark was calculated on an ovendry weight-water immersed volume basis. Moisture content was determined on an ovendry basis after drying to a constant weight at 103°C. Mean tree moisture content and specific gravity were calculated by weighting sample disk values by the volume of material each disk represented.

ANALYSIS

Standard analysis of variance techniques for a randomized complete block design were used to evaluate species differences on each site type. Treatment means (species means) were compared using Scheffe's multiple-comparison procedure.

Table 1.--Means and ranges for aboveground tree measurements for each species of southern pine sampled.

Species	Trees Sampled	DBH Average	DBH Range	Total Height[1/] Average	Total Height[1/] Range	Age
	Number	----Inches----		-----Feet----		Years
			Dry Site			
Loblolly	12	5.4	2.3 - 8.1	46	23 - 59	26
Slash	12	6.0	3.1 - 8.6	50	28 - 65	26
Longleaf	12	6.1	3.2 - 8.8	51	31 - 66	26
Shortleaf	12	4.9	1.9 - 8.5	44	23 - 62	26
			Intermediate Site			
Loblolly	12	6.7	4.6 - 8.8	58	49 - 64	27
Slash	12	7.9	3.0 - 10.5	59	37 - 71	27
Longleaf	12	6.3	3.0 - 8.5	56	37 - 68	27
Shortleaf	12	6.6	4.9 - 9.8	60	55 - 66	27
			Wet Site			
Loblolly	12	6.4	4.7 - 8.3	54	42 - 64	25
Slash	12	6.5	3.8 - 9.5	58	43 - 70	25
Longleaf	12	5.0	2.4 - 7.4	44	24 - 63	25
Shortleaf	12	4.0	2.3 - 6.7	30	17 - 40	25

1/Figures represent average heights from groundline to apical tip.

Table 2.--Means and ranges for belowground tree measurements for each species of southern pine sampled.

Species	Trees Sampled	Maximum Taproot d.o.b. Average	Maximum Taproot d.o.b. Range	Root Length[1/] Average	Root Length[1/] Range	Age
	Number	----Inches----		----Feet-----		Years
			Dry Site			
Loblolly	12	7.7	4.2 - 12.1	6.9	4.8 - 9.7	26
Slash	12	8.9	4.4 - 13.5	6.3	5.2 - 8.5	26
Longleaf	12	8.8	4.6 - 12.9	7.2	4.8 - 11.0	26
Shortleaf	12	6.4	2.8 - 11.3	6.5	3.9 - 10.6	26
			Intermediate Site			
Loblolly	12	9.8	6.5 - 14.3	4.9	3.6 - 6.0	27
Slash	12	11.6	4.0 - 20.0	4.4	2.6 - 5.8	27
Longleaf	12	9.5	4.1 - 14.6	4.2	3.2 - 5.5	27
Shortleaf	12	9.9	6.8 - 14.2	4.6	3.5 - 5.9	27
			Wet Site			
Loblolly	12	9.1	6.8 - 12.0	4.2	3.1 - 5.4	25
Slash	12	9.7	5.3 - 13.0	3.9	2.3 - 5.0	25
Longleaf	12	6.7	3.1 - 9.8	3.2	2.1 - 4.5	25
Shortleaf	12	5.3	3.3 - 7.5	3.1	2.1 - 4.7	25

1/Figures represent average lengths from top of 6-inch high stump to taproot tip.

Linear regression techniques also were used and prediciton equations generated to predict complete tree green weight, dry weight, and cubic volume from taproot tip to apical tip. Complete tree weights and volumes were fitted to the linearized form of the allometric model:

$$\log Y = b_o + b_1 \log (D^2H)$$

where: Y = weight (pounds) or volume (cubic feet)
D = d.b.h. in inches
H = total height in feet
log = base 10 logarithm
b_o, b_1 = coefficients estimated from the data

The b_o coefficients of the various equations were corrected for bias resulting from transforming log Y to Y (Baskerville 1972, Flewelling and Pienaar 1981) by using a procedure given in Yandle and Wiant (1981) and outlined by Baldwin and Saucier (1982).

RESULTS

Analysis of Variance

The means for aboveground and belowground measurements on all three sites are presented in tables 1 and 2, the results of the analysis of variance for these same variables on the dry and intermediate sites indicated the species differences were not significant at the 5% level. The analysis of variance for the wet site, however, showed significant species differences for all variables examined (table 3).

Slash pine demonstrated consistently higher values than loblolly, longleaf, or shortleaf pines, when wet site species means were ranked for each of the variables (d.b.h., total height, maximum taproot d.o.b., complete tree green weight, complete tree dry weight, and complete tree volume) in the analysis of variance in table 3. The exception to this trend occurred for stump-taproot length where the mean value for loblolly pine exceeded that of slash pine. Shortleaf pine consistently produced the lowest mean values for all variables.

A comparison of these species means on the wet site using Scheffe's multiple-comparison procedure

Table 3.--Results of analysis of variance and Scheffe's mean comparison for species differences on the wet site.[1]

Analysis of Variance		Scheffe's Mean Comparison[3]			
Dependent Variable	PR>F[2]	SL	LB	LL	SH
dbh (inches)	.0004	6.5a	6.4a	5.0ab	4.0b
total height (feet)	.0001	58.2a	53.5ab	43.7b	30.1c
maximum root d.o.b. (inches)	.0001	9.7a	9.1ab	6.7bc	5.3c
stump-taproot length (feet)	.0020	3.8ab	4.2a	3.2b	3.1b
complete tree green weight (pounds)	.0001	502.9a	404.7a	268.9ab	104.6b
complete tree dry weight (pounds)	.0001	257.6a	209.4a	134.0ab	52.7b
complete tree volume (cubic feet)	.0001	9.5a	7.5a	4.8ab	1.9b

[1] Analysis of variance for RCB design with 3 blocks of 4 species (based on 48 trees, 12 of each species.

[2] The significance probability associated with the F value.

[3] Figures represent the average of 12 trees for each species. Means in the same row followed by the same letter are not significantly different at the $\alpha = 0.05$ level. SL = slash pine, LB = loblolly pine, LL = longleaf pine, and SH = shortleaf pine.

Table 4.--Regression coefficients for predicting complete tree green weight, dry weight, and volume of each of the four major southern pines on each site and supporting statistics: $\log Y = b_o + b_1 \log(D^2H)$.[1/]

Dependent Variable (Y)	Species	Regression Coefficients[2/] b_o	b_1	Statistics[3/] r^2	$S_{y \cdot x}$
		Dry Site			
Green Weight (pounds)	Loblolly	-0.55782	0.95070	.963	.08804
	Slash	-0.53858	0.94853	.978	.05400
	Longleaf	-0.60967	0.98412	.989	.06435
	Shortleaf	-0.73622	1.02344	.979	.05431
Dry Weight (pounds)	Loblolly	-0.81796	0.94538	.971	.07799
	Slash	-0.78412	0.93951	.986	.04214
	Longleaf	-0.76701	0.94642	.991	.05649
	Shortleaf	-0.95063	0.99922	.985	.04511
Volume (cubic feet)	Loblolly	-2.19612	0.92357	.983	.05734
	Slash	-2.25977	0.95110	.985	.04494
	Longleaf	-2.28140	0.95729	.990	.05912
	Shortleaf	-2.32767	0.97663	.969	.06300
		Intermediate Site			
Green Weight (pounds)	Loblolly	-1.12460	1.10125	.940	.06906
	Slash	-0.99243	1.06515	.992	.04105
	Longleaf	-0.79925	1.02065	.988	.04217
	Shortleaf	-0.94415	1.06514	.975	.03475
Dry Weight (pounds)	Loblolly	-1.23356	1.05643	.956	.05623
	Slash	-1.02230	1.00350	.991	.03939
	Longleaf	-1.03469	1.00088	.984	.04683
	Shortleaf	-1.12050	1.03756	.953	.04703
Volume (cubic feet)	Loblolly	-2.62616	1.04198	.979	.03799
	Slash	-2.60673	1.04185	.993	.03754
	Longleaf	-2.42670	0.98606	.989	.03824
	Shortleaf	-2.70781	1.06791	.979	.031773
		Wet Site			
Green Weight (pounds)	Loblolly	-1.10800	1.10410	.975	.04025
	Slash	-1.08544	1.09823	.986	.04428
	Longleaf	-0.79982	1.02995	.993	.03790
	Shortleaf	-0.55310	0.94054	.978	.05015
Dry Weight (pounds)	Loblolly	-1.50236	1.13616	.969	.04626
	Slash	-1.26605	1.10666	.986	.04238
	Longleaf	-1.11532	1.03441	.993	.03919
	Shortleaf	-0.76039	0.90864	.976	.05029
Volume (cubic feet)	Loblolly	-2.49470	1.00318	.973	.03798
	Slash	-2.52917	1.01851	.994	.02650
	Longleaf	-2.36676	0.97468	.989	.04698
	Shortleaf	-2.15545	0.89458	.965	.06029

1/Complete tree green weight and dry weight consist of all wood and bark in the stump-taproot, stem, and crown including foliage. Complete tree volume consists of all wood and bark in the taproot, stem, and crown excluding foliage. D = dbh in inches, H = total height in feet, log = base 10 logarithm.

2/b_o coefficients have been corrected for bias occurring when transforming log Y to Y. Equations are based on 12 trees per species per site.

3/r^2 is the coefficient of determination for the log form of the equation. $S_{y \cdot x}$ is the standard error of the estimate for the log form of the equation.

(table 3) revealed shortleaf pine was significantly lower in all variable values than slash and loblolly, except for stump-taproot length. In this case, shortleaf produced a significantly shorter taproot than loblolly, but was not significantly shorter than slash or longleaf. Species comparisons of complete tree green weight, dry weight, and volume indicated slash, loblolly, and longleaf pines were not significantly different in value. Longleaf and shortleaf were not significantly different either, but slash and loblolly were significantly greater in value than shortleaf.

PREDICTION EQUATIONS

Coefficients of equations for predicting complete tree green weight, dry weight, and volume for each species on each site are presented in table 4. Also presented in table 4 are the supporting goodness of fit statistics, coefficient of determination (r^2) and standard error of the estimate ($Sy \cdot x$).

The high values of r^2 indicate a strong relationship between weight and volume and the independent variable D^2H. Tree d.b.h. and total height account for 94.0 to 99.4 percent of the variation in complete tree weight and volume for the four species on the three sites.

These results are preliminary in that only equations to predict complete tree green weight, dry weight, and volume were presented. Development of equations to predict tree component weights and volumes is currently in progress. Additionally, anatomical characteristics, such as fiber length and width, transverse cell dimensions, and growth rates are being investigated. An examination of mechanical properties, such as strength in static bending, compression parallel-to-grain, and toughness is proposed also.

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ABOVEGROUND BIOMASS OF PLANTED AND DIRECT-SEEDED SLASH PINE IN THE WEST GULF REGION[1/]

RICHARD E. LOHREY[2/]

Abstract.--Equations are presented for estimating total green or dry weight of stems or crowns (inside or outside bark) and the ratio of merchantable stem weight to total stem weight. Separate equations for trees established by planting and direct seeding on cutover forest sites in the West Gulf Region are compared.

INTRODUCTION

Although trees have traditionally been measured by volume, it has long been recognized that weight is a better measure than volume for some products such as fuel. Recent energy shortages and the economic advantages of using wood have stimulated interest in its use as fuel and in the use of weight as a measure of wood quantity. In addition, weight is the most logical means of measuring small irregularly shaped pieces such as those found in limbs and small stems. The continuing trends toward more intensive forest management and full tree utilization have further stimulated interest in the use of weight as a measure of wood quantity. This paper presents equations for estimating the green and dry aboveground weight of artificially regenerated slash pines (Pinus elliotti Engelm. var. elliottii) on cutover forest sites in Louisiana.

METHODS

Sample trees were selected mainly within permanent growth and yield plots scattered throughout Louisiana. They represent a wide array of sites, ages, stand densities, and silvicultural treatments (table 1). Additional stands on National Forests and industrial lands were also sampled. Characteristics of the sample trees are given in table 2. Their distribution by site index and age classes is shown in tables 3 and 4.

Table 1.--Characteristics of sample stands

Item[1/]	Unit	Mean	Range
Planted stands			
Site index(25)	Feet	60	31-78
Age from planting	Years	31	12-48
Trees/acre	Number	468	51-2,186
BA/acre	Sq. ft.	119	48-217
Direct-seeded stands			
Site index(25)	Feet	59	30-70
Age from seeding	Years	19	13-26
Trees/acre	Number	1,096	330-3,580
BA/acre	Sq. ft.	132	17-204

1/ BA = Basal area.

Table 2.--Characteristics of sample trees

Item[1/]	Unit	Mean	Range
Planted trees (201)			
DBH	Inches	8.2	2.2-19.1
Height	Feet	59	20-110
Age from planting	Years	31	12-48
LCR	Percent	33	11-60
Direct-seeded trees (267)			
DBH	Inches	5.7	1.3-12.1
Height	Feet	46	12-76
Age from seeding	Years	19	13-26
LCR	Percent	36	11-58

1/ LCR = Live crown ratio.

1/ Paper presented at the Sixth Annual Southern Forest Biomass Workshop, Athens, Georgia, June 5-7, 1984.
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Table 3.--Distribution of planted trees by site index and age class

Age class (years)	Site index(25) <49	50-65	>66	Row total
	Number of trees			
< 24	9	18	57	84
25-40	27	27	16	70
> 41	6	28	13	47
Column total	42	73	86	201

Table 4.--Distribution of direct-seeded trees by site index and age class

Age class (years)	Site index <49	50-65	>66	Row total
	Number of trees			
< 15	21	37	10	68
16-21	17	13	42	72
> 22	7	99	21	127
Column total	45	149	73	267

Crown class and outside-bark diameter at heights of 0.5, 2.0, and 4.5 feet were recorded before each sample tree was felled. After felling, six live sample branches were selected from along the bole--two from the lower one-third of the crown, two from the middle one-third, and two from the top one-third. The six sample branches were cut from the stem, and the length, diameter, and total green weight with foliage of each was determined and recorded. The branches were reweighed after foliage was removed. Samples of foliage and branches were sealed in polyethylene bags and kept in cold storage until laboratory analyses.

After the six sample branches were weighed, the remaining branches were cut from the stem and their total combined weight was determined.

After all branch measurements were completed, the main stem was measured, sectioned, and weighed. Bucking points were marked at 5-foot intervals and the height and outside-bark diameter recorded for each point. Shorter bolts were cut where stem taper was extreme or irregular, such as below breast height or high in the crown. After each bolt was weighed, a 1.5-inch-thick disk was cut off the bottom end, labeled with the tree and bolt or disk number, sealed in double plastic bags, and kept in cold storage until laboratory analyses.

In the laboratory, the inside-bark diameters of stem disks were measured. Green volume and both green and oven dry weights were determined for stemwood, stembark, branchwood, and branchbark samples. Green and oven dry weights were determined for foliage samples. All samples were dried in a forced-air oven at 105°C until weight loss was completed.

ANALYSIS OF DATA

Tree volume and weight data were analyzed by linear and nonlinear [modifed Gauss-Newton algorithm (SAS Institute 1982)] regression methods. The equations were evaluated with respect to their ability to predict whole tree or individual component weights. Separate sets of coefficients were determined for planted and direct-seeded trees and also for the combined data. Differences between the regression lines for planted and direct-seeded trees were tested by the general linear test procedure described by Neter and Wasserman (1974). Their general approach tests the equality of two regression functions and does not compare slopes or intercepts.

RESULTS

Stem Weights

The model used to estimate stemwood and stembark weights was suggested by Schumacher and Hall (1933) for stem volume. Their model is:

$$\hat{V} = b_1 D^{b_2} H^{b_3}, \tag{1}$$

where $\hat{V}$ = predicted stem volume,

D = outside-bark diameter at 4.5 feet in inches,

H = total height in feet,

and b_1, b_2, & b_3, = coefficients estimated from the data.

For my green and dry weight equations, I used:

$$\hat{W} = b_1 D^{b_2} H^{b_3}, \tag{2}$$

where $\hat{W}$ = predicted weight.

The model was converted to a linear form by logarithmic transformation:

$$\ln(\hat{W}) = \ln(b_1) + b_2 \ln(D) + b_3 \ln(H), \tag{3}$$

$$\ln(\hat{W}) = b_1' + b_2 \ln(D) + b_3 \ln(H), \tag{4}$$

where ln = natural logarithm.

Data from 201 planted and 267 direct-seeded trees were used to fit the equations. The equations may be used to estimate the green or dry weight of stems (inside or outside bark) from a 6-inch stump to the tip for trees of given diameter and height. Coefficients for stem weight equations are given in table 5. The b_1 has been adjusted to compensate for the bias that is introduced when transforming log Y to Y (Finney 1941). This adjustment followed the procedures recommended by Baskerville (1972) and Yandle and Wiant (1982).

Merchantable Weight Ratios

Merchantable weights may be estimated from total stem weights and weight ratio equations. Ratio equations give the proportion of total weight below a given merchantable upper stem diameter limit. The model I used was previously used by Parresol (1983). It is:

$$\hat{R} = \mathrm{EXP}[b_1(d^{b_2}/D^{b_3})] \; , \qquad (5)$$

where $\hat{R}$ = estimated ratio of merchantable to total weight,

Table 5.--Coefficients for total stem weight equations[1/]

Dependent variable[2/]	Parameter estimates			Statistics[3/]		
	b'_1	b_2	b_3	Fit index	S.E.	C.V.
			Planted trees			
TGWob	-2.00410	2.10282	0.96566	0.99	111.24	12.64
TGWib	-2.78724	2.09631	1.12132	.98	147.81	19.22
TDWob	-2.52002	2.07746	.95970	.99	68.54	14.06
TDWib	-3.83950	2.04678	1.24004	.99	63.55	15.69
			Direct-seeded trees			
TGWob	-1.83301	2.00091	0.97750	.99	31.03	10.48
TGWib	-2.61214	1.99736	1.13043	.98	31.01	13.04
TDWob	-2.34624	1.96166	.95760	.99	15.19	10.37
TDWib	-3.93020	1.89733	1.32038	.98	15.51	13.31
			Combined data			
TGWob	-1.85287	2.04301	0.96159	.99	78.69	14.37
TGWib	-2.62832	2.03992	1.11353	.98	93.37	19.94
TDWob	-2.43654	2.03537	.95437	.98	60.58	20.55
TDWib	-3.92748	1.98200	1.28791	.98	51.44	21.28

[1/] The model is:

$$\ln(\hat{w}) = b'_1 + b_2 \ln(D) + b_3 \ln(H)$$

where $\hat{W}$ = predicted stem weight (pounds) from a 6-inch stump to the tip,
D = diameter outside bark (inches) at 4.5 feet,
H = total tree height (feet),

and b'_1, b_2, b_3 = Coefficients estimated from the data.

[2/] TGWob = total green weight outside bark.
TGWib = total green weight inside bark.
TDWob = total dry weight outside bark.
TDWib = total dry weight inside bark.

[3/] Fit index = $\{1-[\Sigma(Y_i - \hat{Y}_i)^2]/[\Sigma(Y_i - \bar{Y})^2]\}$.

S.E. = standard error in the original units.
C.V. = coefficient of variation in percent.

d = merchantable upper stem limit (inches),

D = diameter at 4.5 feet (inches),

EXP = exponential function,

and b_1, b_2, b_3 = coefficients estimated from the data.

The data were fitted to the model by nonlinear regression methods. The resulting stem weight ratio equations may be used with the total stem weight equations given above to estimate green or dry weight (inside or outside bark) for any upper stem diameter (inside or outside bark) limit that the user may specify. Equation coefficients for stem weight ratio equations are given in Table 6.

Crown Weights

Weight data for the crown (lateral branches and foliage) and its various components (wood, bark, and foliage) were fitted to model 4. The resulting equations estimate green or dry weight of the tree crown or individual components. Coefficients for crown weights are given in Tables 7 and 8.

Comparisons Between Stand Origins

Regression lines for the two stand origins were tested for six independent variables, including total green and dry weights of stems (inside and outside bark) and total green and dry weights of crowns. In each of the six comparisons, the difference between regression lines for planted and direct-seeded trees was statistically significant at the 0.05 level.

The differences in predicted weight for planted and direct-seeded trees were small for trees 6 to 10 inches in diameter. Predictions were higher for planted than for direct-seeded trees when diameters exceeded 12 inches. But the largest direct-seeded tree sampled was only 12.1 inches in diameter at breast height (DBH). Thus, the largest differences occurred beyond the range of data for these trees. Readers may use equation coefficients that apply to their particular situation or those for the combined data that are more universally applicable.

EXAMPLES

The examples below illustrate use of the equation coefficients presented above.

Suppose someone wanted to estimate the merchantable green weight of stem to a 4-inch (outside-bark diameter) top, total green weight of stem, and total green weight of tree for a planted tree with a DBH of 10 inches and total height of 70 feet.

The total green weight (TGWob) of a stem can be estimated using coefficients from Table 5:

$$\begin{aligned} \text{TGWob} &= \text{EXP}\ [b_1' + b_3 \ln(D) + b_3 \ln(H)] \\ &= \text{EXP}\ [-2.00410 + 2.10282 \ln(10) + 0.96566 \ln(70)] \\ &= \text{EXP}\ [6.94042] \\ &= 1{,}033 \text{ lb} \end{aligned}$$

The ratio of merchantable to total green weight of a stem (R) can be estimated using coefficients from Table 6:

$$\begin{aligned} R &= \text{EXP}\ [b_1(d^{b_2}/D^{b_3})] \\ &= \text{EXP}\ [-1.37971\ (4^{5.15075}/10^{5.06016})] \\ &= \text{EXP}\ [-1.37971\ (1{,}262/114{,}858)] \\ &= \text{EXP}\ [-0.015159] \\ &= 0.9850 \end{aligned}$$

The merchantable green weight (MGWob) is then estimated by multiplying this ratio times the total green weight of the stem:

$$\begin{aligned} \text{MGWob} &= R \times \text{TGWob} \\ &= 0.9850 \times 1{,}033 = 1{,}017 \text{ lb} \end{aligned}$$

The crown green weight (CGWob) is estimated using coefficients in Table 7:

$$\begin{aligned} \text{CGWob} &= \text{EXP}\ [b_1 + b_2 \ln(D) + b_3 \ln(H)] \\ &= \text{EXP}\ [1.68176 + 3.58663 \ln(10) - 1.10898 \ln(70)] \\ &= \text{EXP}\ [5.22878] \\ &= 187 \text{ lb} \end{aligned}$$

The total tree green weight (TTGWob) is the sum of the green weights of the stem and crown.

$$\begin{aligned} \text{TTGWob} &= \text{TGWob} + \text{CGWob} \\ &= 1{,}033 + 187 \\ &= 1{,}220 \text{ lb} \end{aligned}$$

Table 6.--Coefficients for stem weight ratio equations[1/]

Dependent variable [2/]	Parameter estimates: b_1	b_2	b_3	Statistics[3/]: Fit index	S.E.
			Planted trees		
MGWob/TGWob	-1.37971	5.15075	5.06016	0.97	.05
MGWib/TGWib	-1.41340	5.30576	5.22115	.97	.05
MDWob/TDWob	-1.28207	5.39802	5.30771	.97	.05
MDWib/TDWib	-1.44517	5.49617	5.44349	.97	.05
			Direct-seeded trees		
MGWob/TGWob	-1.06386	4.92558	4.73063	.97	.05
MGWib/TGWib	-1.03948	5.10203	4.88859	.97	.05
MDWob/TDWob	-.90261	5.15925	4.92383	.97	.05
MDWib/TDWib	-.98440	5.26669	5.05225	.97	.05
			Combined data		
MGWob/TGWob	-1.17343	5.02896	4.87624	.97	.05
MGWib/TGWib	-1.16937	5.19419	5.03462	.97	.05
MDWob/TDWob	-1.02826	5.26837	5.09115	.97	.06
MDWib/TDWib	-1.13828	5.36896	5.22104	.97	.06

[1/] The weight ratio model is: $\hat{R} = \text{EXP}\ [b_1(d^{b_2}/D^{b_3})]$,

where $\hat{R}$ = predicted ratio of merchantable to total weight (pounds),
d = merchantable upper stem limit (inches),
D = diameter (inches) at 4.5 feet,
and b_1, b_2, and b_3 = coefficients estimated from the data.

[2/] MGWob = merchantable green weight outside bark.
MGWib = merchantable green weight inside bark.
MDWob = merchantable dry weight outside bark.
MDWib = merchantable dry weight inside bark.
TGWob = total green weight outside bark.
TGWib = total green weight inside bark.
TDWob = total dry weight outside bark.
TDWib = total dry weight inside bark.

[3/] Fit index = $\{1-[\Sigma(Y_i - \hat{Y}_i)^2]/[\Sigma(Y_i - \bar{Y})^2]\}$

S.E. = standard error in the original units.

Table 7.--Coefficients for crown green weight equations[1/]

Dependent variable [2/]	Parameter estimates b'_1	b_2	b_3	Statistics[3/] Fit index	S.E.	C.V.
			Planted trees			
TCGW	1.68176	3.58663	-1.10898	0.88	80.72	46.96
CGWW	-.33607	3.88499	-1.00945	.89	40.06	52.58
CGWB	-.42157	3.56931	-.97321	.89	17.95	48.21
CGWF	1.76752	3.31231	-1.20636	.60	40.54	69.31
			Direct-seeded trees			
TCGW	2.76733	3.57939	-1.34195	0.91	21.89	33.39
CGWW	.15990	3.75864	-1.04070	.90	9.48	40.58
CGWB	.30603	3.52372	-1.10366	.90	5.05	38.41
CGWF	3.03520	3.49122	-1.56317	.87	10.21	35.10
			Combined data			
TCGW	2.56836	3.54584	-1.28833	.90	51.87	47.28
CGWW	.14610	3.77866	-1.05828	.91	25.84	57.06
CGWB	.19295	3.51414	-1.08139	.90	12.02	51.96
CGWF	2.82465	3.35394	-1.46383	.68	27.67	67.02

[1/] The model is:

$$\ln(\hat{w}) = b_1' + b_2 \ln(D) + b_3 \ln(H),$$

where $\hat{W}$ = predicted weight (pounds) of the crown component,
D = diameter (inches) of the stem outside bark at 4.5 feet,
H = total tree height in feet,
and b_1', b_2, and b_3 = coefficients estimated from the data.

[2/] TCGW = total crown green weight.
CGWW = crown green weight of wood.
CGWB = crown green weight of bark.
CGWF = crown green weight of foliage.

[3/] Fit index = $\{1-[\Sigma(Y_i - \hat{Y}_i)^2]/[\Sigma(Y_i - \bar{Y})^2]\}$.

S.E. = standard error in the original units.
C.V. = coefficient of variation in percent.

Table 8.--Coefficients for crown dry weight equations[1/]

Dependent variable [2/]	Parameter estimates b_1'	b_2	b_3	Statistics[3/] Fit index	S.E.	C.V.
			Planted trees			
TCDW	1.05660	3.58076	-1.14336	0.90	33.53	42.14
CDWW	-1.28789	3.79139	-.91566	.91	17.00	47.83
CDWB	-.90635	3.48826	-.98807	.90	8.32	45.61
CDWF	1.11607	3.32102	-1.25074	.58	17.85	68.95
			Direct-seeded trees			
TCDW	1.61033	3.45566	-1.19654	0.91	9.61	33.25
CDWW	-1.16988	3.56330	-.81706	.89	4.36	42.22
CDWB	-.60760	3.34800	-.98798	.87	2.52	42.67
CDWF	1.94351	3.42979	-1.46739	.88	4.32	34.06
			Combined data			
TCDW	1.56380	3.48304	-1.20611	.92	21.27	42.64
CDWW	-1.10093	3.63966	-.87605	.92	11.11	53.51
CDWB	-.65531	3.40205	-1.00250	.91	5.73	52.13
CDWF	1.87412	3.32538	-1.41824	.67	12.15	66.98

[1/] The model is:

$$\ln(\hat{w}) = b_1' + b_2 \ln(D) + b_3 \ln(H),$$

where $\hat{W}$ = predicted weight (pounds) of the crown component,
D = diameter (inches) of the stem outside bark at 4.5 feet,
H = total tree height in feet,
and b_1', b_2, and b_3 = coefficients estimated from the data.

[2/] TCDW = total crown dry weight.
CDWW = crown dry weight of wood.
CDWB = crown dry weight of bark.
CDWF = crown dry weight of foliage.

[3/] Fit index = $\{1-[\Sigma(Y_i - \hat{Y}_i)^2]/[\Sigma(Y_i - \bar{Y})^2]\}$.

S.E. = standard error in the original units.
C.V. = coefficient of variation in percent.

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BIOMASS AND NUTRIENT DISTRIBUTION OF *ROBINIA PSEUDOACACIA* L. GROWN UNDER INTENSIVE CULTURE[1/]

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Abstract.--Black locust plantations were established to determine the influence of cultural practices, including fertilization and spacing density, and harvesting utilization on dry matter yields and nutrient dynamics. Maximum yields were attained after 3, 4 and 5 years for plantation spacings of .5 x 1, 1 x 1 and 2 x 1 m. Fertilization significantly influenced dry matter production in the .5 x 1 m spaced plots for 3 years and enhanced N-fixation of locust at all spacings. When compared to wider spaced plantings, trees in closely spaced plots had greater proportion of the biomass distributed to the stem and less to branches and foliage. Frequent harvest may deplete the soil P available to maintain long-term productivity. Frequent P applications may be necessary on marginal sites and/or when the soil has a high P-fixing potential.

INTRODUCTION

Wood is the largest biomass energy resource in the United States and its importance as an alternate or supplemental fuel is dramatized by recent fossil fuel shortages. The Office of Technology Assessment (1980) indicates woody biomass, in addition to its traditional uses, will play a major role in future energy production through gasification or conversion to liquid fuels. In the short run, most of the energy resource needs from biomass is expected to come from residues in conventional harvesting but an increase in the intensity of forest management, including the establishment of biomass/silage plantations, may be essential to achieve the projected energy yield from wood while maintaining the supply of material to forest industries.

Closely spaced, short rotation and intensively cultured fiber plantations can contribute large quantities of biomass ranging from 7-15T/ha/yr (McAlpine et al., 1966; Wittwer et al., 1978). Factors which influence fiber yields include site (Wittwer et al., 1978); site preparation (Carter and White, 1970); planting stock (Kennedy, 1972; Belanger and Saucier, 1975); spacing (Belanger and Pepper, 1978; Wittwer et al., 1978); cultural treatments, including weed control and fertilization (Blackmon and White, 1972); harvesting interval (Belanger and Saucier, 1975; Kennedy, 1975; Perala, 1979); and season (Clark, 1975; Belanger, 1979). In addition, efforts have been made to determine the productive potential of root stocks (Belanger, 1979; Perala, 1979) and to assess the impacts of short rotations and intensive harvesting on long-term site productivity (Blackmon, 1979; DeBell and Radwan, 1979).

In many areas of the country, sites relegated for forestry use are stressful and are marginally productive. In the midwestern United States, most of the lands which are potentially available for the establishment of woody biomass plantations fall into this marginally productive category. If biomass plantations are established in this area, information concerning the productivity of these marginal lands is essential. Black locust (*Robinia pseudoacacia* L.) was selected for investigation because it is a pioneer species capable of rapid growth over a range of soil and site conditions and it responds to cultural treatments. The objectives of this study were to determine the influence of cultural practices, including fertilization and

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spacing density, and harvesting utilization on dry matter yields and nutrient dynamics in black locust biomass plantations.

MATERIALS AND METHODS

Site Selection

The marginal farmland site was located in Tippecanoe County, Indiana on a somewhat poorly drained Fincastle silt loam soil (Aeric, Ochraqualfs [typic] fine-silty, mixed mesic), with 1-3% slope and site index[3/] of 22 to 25 m for yellow poplar (Liriodendron tulipifera L.). The site had been in continuous corn production for approximately ten years, left fallow for 2 years, then plowed and disced prior to tree planting.

Spacing and Fertilization

One-year-old bareroot black locust seedlings were planted by 15 May 1979 in pure stands at densities equivalent to 5,000, 10,000 and 20,000 plants per ha, representing spacing of 2 x 1, 1 x 1, and 0.5 x 1 m, respectively.

Following site preparation soil samples 0-30 cm in depth were collected at 25 random locations and analyzed for chemical properties. Similarly, soil samples were collected in September each year from one random location in each of the 36 subplots on each site and analyzed. Available soil P was determined colorimetrically using ammonium molybdate reagent following extraction with Bray I solution, available K, Ca and Mg were determined by atomic absorption following extraction with 1 N ammonium acetate and available NH_4-N and NO_3-N and total N were determined by 2 N KCL extraction and wet digestion, respectively, and distillation.

Fertilizer treatments, applied in May 1979, consisted of no fertilizer or a broadcast application of P and K at rates equivalent to 100 kg/ha of elemental P and 300 kg/ha elemental K. Phosphorus was applied as super phosphate and potassium as potash. Competing herbaceous and woody vegetation was controlled by cultivation down the rows in mid-June of both growing seasons followed by mowing in early July and August.

Experimental Design

At each location, two fertilizer treatments were randomized over three blocks forming six main plots. Three spacings were randomly assigned to subplots within each main plot. Each subplot was 12 x 12 meters. All trees in the center of 32 m^2 of each subplot (net plots) were measured. This arrangement provides for a minimum of 27 measurement trees for the 2 x 1 m spacing, 45 trees for the 1 x 1 m spacing and 81 trees for the 0.5 x 1 m spacing. Inherent with spacing studies is the necessity of choosing between unequal subclass numbers when a unit area constitutes the measurement plot or risking heterogeneity of variance if surface area varies. The study was arranged in a randomized complete block design and analyses based on unequal sample size.

Data Acquisition and Analysis

Stem height, diameter at 10 cm height and survival were determined annually in September for all net plot trees. To determine the influence of rotation length and harvesting intensity on biomass production and nutrient drain, ten interior border row stems were harvested from each subplot in September after each growing season. Physical measurements included the green and oven dry weight of the foliage and stem and branches. Chemical measurements included N, P and K concentrations of the foliage, and stem and branch components. Nitrogen was determined by semi-micro-kjeldahl technique, phosphorus by ammonium-molybdate-vanadate indicator and potassium by atomic absorption. Biomass and N, P and K concentration of the weed component was determined by sampling a 0.5 x 0.5 m square located at random within each of the harvested six tree rows.

Data were tested by analysis of variance (ANOVA) and those variables found significant were subjected to Duncan's new multiple range test. Weights of total and component biomass of the net plot trees were estimated using the linear regression model

$$\log \lambda = a + b \log x$$

where the lower case letters are constants and x was the combined variable d^2h (d = stem diameter at 10 cm height and h = total stem height).

RESULTS AND DISCUSSION

Plantation Survival

Plantation survival averaged 96 percent and was not influenced by planting density (i.e., spacing) through the first 3 growing seasons (Table 1). The significant decline in survival in both the 0.5 x 1 m and the 1 x 1 m spaced plantings in 1982 and 1983 (4th and 5th growing seasons) was caused by the death of overtopped, suppressed stems and severe plant moisture stress induced by the 1983 drought which also caused mortality in intermediate and dominant stems. Mortality had reduced the stand densities of the 0.5 x 1 and 1 x 1 m spaced planting to 17,400 and 9,100 stems/ha, respectively, in

[3/] Site index is determined at a base age of 50 years.

1982 and 16,000 and 8,600 stems/ha in 1983. Stand density in the 2 x 1 m spaced plantings remained unchanged at 4,800 stems/ha.

Table 1.--Influence of initial spacing on survival of black locust plantations grown under intensive culture.

Spacing (m)	Year 1979-1981	Year 1982	Year 1983
.5x1	96	87a[1/]	80a
1x1	96	91ab	86b
2x1	96	96b	96c

[1/]For a particular year, values not followed by the same letter are significantly different by Duncan's new multiple range test (α = 0.05).

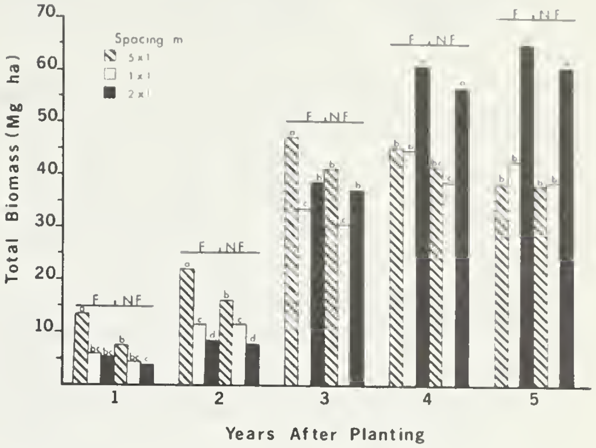

Figure 1.--Influence of fertilization and spacing on total accumulated biomass of live stems of black locust. Note: For a given year values not followed by the same letter are significantly different by Duncan's new multiple range test (α = 0.05).

Dry Matter Accumulation and Distribution

Total biomass, as reported in this paper, is a function of the accumulated dry matter in the stems and branches and the current year's foliage and was determined on a live stem basis, i.e., dead trees were not included in the calculations. Total biomass (fig. 1) was significantly influenced by spacing and fertilization. The greatest amount of biomass was produced by the most closely spaced planting (0.5 x 1 m) for years 1-3 and by the most widely spaced planting (2 x 1 m) in years 4-5. The decline in total biomass of live stems in plots at the 0.5 x 1 m spacing after 3 years and in plots at 1 x 1 m spacing after 4 years reflect increases in plot mortality and lower dry weights of individual stems when compared to the stems in the 2 x 1 m spaced plots. Averaged over fertilizer treatment, the annual biomass increments (mg/ha) of the 0.5 x 1 m spaced plots from 1979-83 were 8.8, 24.9, -2.2, and -5.0; the 1 x 1 m spaced plots averaged 6, 20, 10, and -1.0; the widest spacing, 2 x 1 m averaged 3.7, 29.3, 20.5, and 3.8. From these data, harvest schedules to maximize total biomass yields appear to be linked to initial spacing and should be performed after 3 to 4 years for the closest spacing, 0.5 x 1 m, and at 4 to 5 years for intermediate spaced plots, i.e., 1 x 1 m. Projected rotation length for the widest spacing in this study, 2 x 1 m, is for 5 to 6 years.

Fertilization significantly increased total biomass production in years 1-3 for the most closely spaced planting. Fertilized plots for the other spacings tended to have greater total biomass but the differences were not significant. Fertilization resulted in total biomass increases in the 0.5 x 1 m spaced plots of 5.3, 5.6, 6.1, 3.4, and 0.2 mg/ha from 1979 to 1983. By comparison, fertilization resulted in yield increases of 1.6, 0.3, 3.3, 6.2, and 4.1 mg/ha in the 1 x 1 m spaced plots and 1.5, 0.3, 1.8, 3.8, and 4.7 mg/ha in the 2 x 1 m spaced plots for the same time periods. The lack of response to fertilization in the intermediate and wide spaced plantings may have resulted from an increase in weed competition during the first and second growing seasons; weed competition was not present in the 0.5 x 1 m spaced plantings.

The accumulated dry weight of the stem and branch components followed a pattern demonstrated by the data for total biomass (Table 2). Plot dry weight was greatest for the 0.5 x 1 m spacing from 1979-1981 and for the 2 x 1 m spaced plots in 1982-83. The increased mortality in the 0.5 x 1 and 1 x 1 m spaced plots in 1982-83 was, in part, responsible for the decline in dry weight accumulation. Fertilization significantly improved the dry weight of the 0.5 x 1 m spaced plots in 1979-81 and the 1 x 1 m plots in 1979 and 1982.

There was no difference in the distribution of dry weight among stem, foliage and branch components for any of the spacings in 1979-80 or for the fertilizer treatment throughout the 5 year report period (Table 3). By the end of the

Table 2.--Dry weight (Kg/ha) of the combined stem and branch components of black locust from 1979-1983. Plots were fertilized (F) or received no fertilizer (NF) and varied in spacing.

	Year									
	1979		1980		1981		1982		1983	
Spacing (m)	F	NF	F	NF	F	NF	F	NF	F	NF
.5x1	8.2a[1/]*[2/]	5.3a	16.1a*	12.0a	41.2a*	35.6a	39.6a	36.4a	34.3a	34.2a
1x1	3.96b*	2.9b	8.5b	8.4b	26.9c	24.4c	38.4a*	33.0a	36.3a	32.7a
2x1	3.6b	2.6b	6.1c	6.0c	30.2b	28.9b	49.3b	46.3b	52.7b	49.1b

[1/]For a specific year and fertilizer treatment values not followed by the same letter are significantly different by Duncan's new multiple range test ($\alpha = 0.05$).

[2/]For a specific year and spacing treatment, values for the fertilizer treatment (F) followed by an asterisk (*) are significantly different from the no fertilizer treatment (NF) by Students' T test ($\alpha = 0.05$).

Table 3.--Distribution of aboveground biomass of black locust plantations grown for 5 years at variable spacing. (Summarized by year).

Plant			1981			1982			1983		
Component	1979	1980	.5x1	1x1	2x1	.5x1	1x1	2x1	.5x1	1x1	2x1
Stem	66[1/]	74	62	52	47	67	61	56	61	54	58
Foliage	33	26	13	19	22	12	14	19	10	15	19
Branch			25	29	31	21	25	25	29	31	23

[1/]Values for stem include both stem and branch components for 1979 and 1980.

Table 4.--Influence of fertilization on the concentration of nitrogen and potassium in the stem and foliage tissue of black locust.

	1979		1980		1981		1982		1983	
	Stem	Foliage	Stem	Foliage	Stem	Foliage	Stem	Foliage	Stem	Foliage
% Nitrogen										
Fertilized	1.35	2.90	1.37	2.89	1.35a[1/]	2.81a	1.27	3.04a	1.19	3.01a
Not Fertilized	1.35	2.90	1.37	2.89	1.08b	2.53b	1.11	2.61b	1.10	2.60b
% Potassium										
Fertilized	0.90	0.97	0.84	1.11	0.90	1.15a	0.87	1.18a	0.91a	1.13a
Not Fertilized	0.90	0.97	0.84	1.11	0.85	0.90b	0.74	0.84b	0.76b	0.90b

[1/]For a specific year, nutrient element and tissue type, values not followed by the same letter are significantly different by Students' T test ($\alpha = 0.05$).

3rd growing season (1981), the foliage component in the 0.5 x 1 m plots averaged 13% of the total aboveground dry weight with 19% distributed to the foliage in the 1 x 1 m plots and 22% in the 2 x 1 m plots. The distribution of dry matter to foliage changed very little for any of the spacings in 1982 and 1983. In spite of the increase in mortality in the 0.5 x 1 m and the 1 x 1 m plots, a relatively dense spacing remained, causing little changes in the distribution of dry matter to the foliage, stem or branch components in either of these two spacings. The distribution of dry matter to the branch and foliage components of the 2 x 1 m spaced plots decreased while the stem component increased.

Tissue Nutrient Concentration and Distribution

Compared to the non-fertilized plots, P and K fertilization at the time of plantation establishment, significantly increased the concentration of N in the stemwood in the 3rd year (1981) and foliage in the 4th and 5th years (Table 4). The concentration of K in the foliage of trees in fertilized plots was greater than that of non-fertilized plots in the 3rd through the 5th years. Values for K concentrations in the stemwood were greater in the 3rd and 5th years. When analyzed separately or as interactive variables with fertilization, plantation age (time) and spacing had no influence on tissue nutrient concentrations. The P concentrations of stem and foliage tissue averaged 0.062% and 0.120%, respectively, and were unaffected by any treatment variable.

The two most plausible reasons for the absence of elevated values in the concentrations of nutrients in locust tissue in fertilized plots for the first 2 growing seasons are (1) the dilution effect and (2) enhanced weed competition in fertilized plots of 1 x 1 and 2 x 1 m spacing. Fertilization of the 0.5 x 1 m spaced plantings resulted in dramatic increases in dry matter production and a probable dilution in tissue nutrient concentrations. In the wider spaced plantings, fertilization resulted in an increase in the amount of weed competition which, in turn, may have been responsible for the lack of higher nutrient concentrations in stem and foliage tissues. By the end of the second year, canopy closure was complete in the 0.5 x 1 and 1 x 1 m plots and 70% in the 2 x 1 m spaced plots. The cycling of nutrients from decomposed tree foliage and weedy understory tissue, without the resurgence of new weed growth, may have resulted in elevated nutrient levels in locust tissue in trees growing in plots previously fertilized.

Phosphorus fertilization of some nitrogen fixing plants enhances the nitrogen fixation process resulting in elevated concentrations of foliar nitrogen (Demeterio et al., 1972). While applications of P fertilizer may not have altered the P concentration of black locust, it appears to have significantly increased the foliar N concentrations, presumably, by stimulating the nitrogen-fixing bacteria. In field observations of the present study, excavated roots of P-K fertilized black locust, on the average, had 3X the number of nodules of unfertilized trees. The nodules of fertilized trees were, on an average, larger (0.65 vs 0.31 cm) and distributed more uniformly along the lateral roots growing in the upper soil profile. The annual distribution of nutrients to the foliage component decreased over time while the distribution to the stem and branch components increased (Table 5). When compared to trees in the 0.5 x 1 m spaced plots for years 3-5, the trees in the 2 x 1 m plots had a greater percentage of nutrients in the foliage component and a lesser percentage in the stem. These differences are reflective of the distribution of dry matter discussed earlier, i.e., greater distribution of dry weight to foliage and lesser to stem in the 2 x 1 m spaced plots compared to the 0.5 x 1 m plots. Following crown closure, the foliage component makes up a relatively small percentage of the dry weight of the aboveground components (12-23%) but represents a substantial portion of the annual nutrient budget (24-37% - N, 21-31% - P and 13-24% - K).

Nutrient Removal

The nutrient removal in biomass harvested from short rotation plantations may have a significant effect on long-term site productivity. The shorter the rotation and the more completely the biomass is harvested, the more severe the drain of certain nutrients from the site (Blackmon, 1979). Nitrogen and phosphorus were the chemical elements identified in multiple regression equations which were significant in predicting the dry weight of seedlings [total dry weight (kg) = b_0 + b_1 (tot. soil N) + b_2 (% foliar N) + b_3 (Bray I extr. soil P); R^2 = 0.63]. The influence of spacing/age and fertilization on the percentage of N and P removed from the soil-plant system for two harvesting intensities is shown in Table 6. The particular spacing/age was selected because, for this study, total biomass was greatest for the combinations indicated. The soil-plant system is defined as the soil to a depth of 30 cm and the aboveground biomass of the crop trees and any other vegetation. Nutrient drain is the difference in the amount and availability of a particular nutrient element in the soil-plant system, and the amount removed from the site in harvesting.

For each spacing/age classification, fertilization with P and K increased the nutrient pool (kg/ha) contained in the aboveground crop tree biomass (Table 6) and therefore the total amount removed by harvesting. Including the foliage component in the harvest increased the amount of elemental N removed by approximately 27% for both fertilized and

Table 5.--Percentage distribution of N, P and K in the aboveground components of black locust plantations planted at three spacings.

Year After Planting	Spacing (m)	Stem N	Stem P	Stem K	Branch N	Branch P	Branch K	Foliage N	Foliage P	Foliage K
1	*	49	54	65	+	+	+	51	46	35
2	*	56	65	68	+	+	+	44	35	32
3-5	0.5x1	55	58	62	22	22	25	24	21	13
	1x1	46	50	53	23	24	27	31	26	20
	2x1	42	47	51	21	22	25	37	31	24

*For years 1 and 2, nutrient distribution was not influenced by spacing.

+Branch component values were combined with stem data.

Table 6.--Influence of fertilization and harvesting utilization on the nutrient content of aboveground biomass in selected spacing/age categories.

	Nutrient Content (kg/ha)				Percent of Nutrient Pool Removed			
	Fert		No Fert		Fert		No Fert	
Spacing 0.5 x 1 m Age 3 Plant Components	N	P	N	P	N	P	N	P
Stem + Branch	593	25	426	26	14	23	11	32
Stem + Branch + Foliage	759	35	541	33	18	32	14	44
Spacing 1 x 1 m Age 4 Plant Components								
Stem + Branch	589	25	440	21	14	27	11	33
Stem + Branch + Foliage	745	33	557	27	18	36	14	50
Spacing 2 x 1 m Age 5 Plant Components								
Stem + Branch	856	33	713	31	19	33	17	40
Stem + Branch + Foliage	1041	47	872	43	23	47	21	57

non-fertilized plots in the 0.5 x 1 m spacing at age 3 and the 1 x 1 m spacing at age 4, and 22% in the 2 x 1 m spacing at age 5. The additional P removed in the foliage for fertilized and non-fertilized plots at the 3 selected space/age classifications were 40 and 27%, respectively, for 0.5 x 1 m/3, 32 and 29% for classification 1 x 1 m/4, and 42 and 39% for 2 x 1 m/5.

The low percentage of nitrogen removed from the soil-plant system is directly related to the nitrogen-fixing capabilities of black locust. Monson (1978) suggested that if N could be partitioned by plant component the entire N content of the aboveground portioned of N-fixing plants could be supplied by the symbiotic relationship. Auten (1945) indicated that well stocked black locust stands added 70 kg-N/ha to the soil annually. Average total soil N content of the pre-planted and pre-fertilized site was 3,206 kg/ha. For each of the spacing/age classifications selected for discussion, the total soil N was greater than the pre-plant and pre-fertilize value. Total soil N averaged 202 and 90 kg/ha greater for fertilized and non-fertilized plots at age 3 at a 0.5 x 1 m spacing, 228 and 131 kg/ha greater after 4 years in fertilized and non-fertilized plots at 1 x 1 m, and 186 and 129 kg/ha greater for fertilized and non-fertilized plots after 5

years at a 2 x 1 m spacing. These increases in total N in the soil component are attributed, in part, to the beneficial effects of the N-fixing locust and the apparent stimulation of N fixation resulting from the P-K fertilizer treatment.

The percentage of P removed from the site through stem and branch harvest is relatively large compared to what is available in the soil-plant system. This percentage becomes even more important if the foliage component is included in the biomass removed. Fertilization was effective in reducing the percentage of P removed from the nutrient pool.

For a single rotation of 3, 4 or 5 years, the largest percentage of P removed from the nutrient pool occurred for a complete aboveground biomass removal in unfertilized stands spaced at 2 x 1 m on a 5 year rotation. Second rotation information is not available but if one assumes a similar nutrient depletion in subsequent rotations, the 0.5 x 1 m spaced unfertilized stands on 3 year rotations would have the greatest impact on P depletion. Prior to fertilization extractable soil P (Bray I) averaged 54.8 kg/ha. After 3, 4 or 5 years at spacings of 0.5 x 1, 1 x 1 and 2 x 1 m, respectively, the fertilized plots had Bray I extractable soil P values of 74, 59 and 53 kg/ha while P values for non-fertilized plots for the same ages and spacings were 41, 37 and 35 kg/ha. The sizable reductions in extractable P values indicate that the extractable P fraction is not being replaced at a rate to keep up with removal, and may represent a limiting factor for the biomass production in subsequent rotations.

SUMMARY

Biomass yields of black locust can be significantly influenced by cultural practices, including initial spacing, fertilization, rotation length, and harvesting intensity (degree of biomass utilization or season of harvest). The total dry weight attained is, in part, a function of total soil nitrogen and extractable soil P. To maintain site productivity for N-fixing plants, adequate levels of available soil P may be essential. Biomass plantations of N-fixing tree species established on marginal sites may require frequent P fertilization if harvest intervals are short and the soil has a high P-fixing potential. Careful investigation of the economics of short rotation plantations is essential before practices can be recommended for large scale plantings.

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CLIMATOLOGICAL VARIATIONS IN ENERGY FOREST YIELDS IN THE CENTRAL GREAT PLAINS OF THE UNITED STATES 1/

W. A. Geyer, G. G. Naughton and K. L. Lynch 2/

Abstract.--A series of experiments on short rotation forestry using six rapid growing species were initiated in 1976. Biomass productivity on cultivated plots after three growing seasons ranged from 0.9 to 13.7 Mg/ha/yr at 3700 trees/ha planting density. Yields generally followed a clinal precipitation pattern. Black locust performed well while three other species show promise.

INTRODUCTION

Woody biomass is an appealing energy source because it is renewable, abundant and environmentally advantageous. While only about 2 percent of the total energy needed in the United States is provided by wood, a four-fold increase is possible within the decade (Zerbe, 1981). One source of wood could come from short rotation forest plantations grown exclusively for energy production. Since the 1960's, the system has been studied extensively in Georgia (McAlpine et al., 1966) and many other areas of the country.

Potential woody biomass productivity rates for the continental United States have been estimated by Ranney, et al. (1982) from numerous Short Rotation Woody Crops (SRWC) studies currently supported by the U. S. Government. Figure 1 shows their projected productivity rates, using optimum stand management strategies and best tree species. Current productivity rates of SRWC observed in the United States, based upon a wide variety of sites, unimproved planting stock, ages, fertilizer levels and weed control regimes, average 6 dry Mg/ha/yr per year. The average yield on commercial forestland is only 2.3 Mg/ha/yr (Rowell, et al., 1982).

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2/Authors are Professor, Professor, and Assistant Professor, respectively, Department of Forestry, Kansas State University, Manhattan, Kansas.

This paper reports the results of biomass productivity studies conducted in Kansas, a part of the Central Great Plains region of the United States, to evaluate fast growing tree species at various stand densities as affected by climatological regimes.

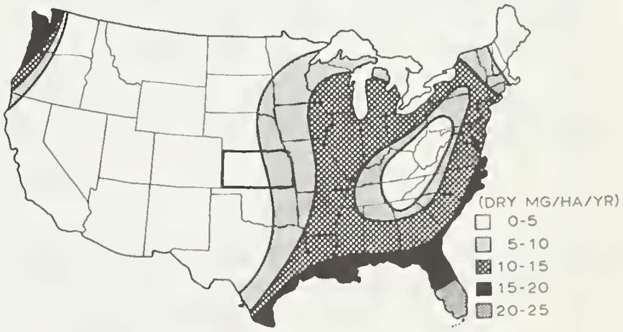

Figure 1.--Potential productivity for short rotation intensive silviculture plantations.

PROCEDURES

Geography, Climate & Natural Vegetation

The study areas investigated lie in the state of Kansas which is between 37^{0} and 40^{0} N latitude and 95^{0} to 102^{0} W longitude. Two major physiographic provinces occupy large portions of the state. The Great Plains Province is found in the western 2/3rds, while the Central Lowlands Province is found to the east. Elevations range from 225 to 1200 meters.

Climate is typical continental, with periodic droughts. Normal annual precipitation is 40 cm. on the western high plains and 102 cm. in the east. Over 70% of this occurs during the growing season which has 150 to 200 frost free days.

Natural vegetation ranges from shortgrass prairie type (tree-less) in the west, through tall-grass prairie and prairie savannah in the central portion of the state, to deciduous broadleaf forest in the east (Self, 1978).

Planting Site & Field Design

Sixteen areas have been planted since 1976 on both alluvial and upland sites on sandy and silty soils (Figure 2). A randomized complete block design was used to test species and weed control at each geographic location. The basic plot unit is a Nelder "wheel" (Namkoong, 1965) with 30 spokes and 7 rings/spoke. Spacing between rings range from 1.1 to 3.6 meters. The inner and outer rings were considered border rows and not measured for productivity yields. All planting stock was 1:0 seedlings. Depending upon site and climatic conditions, at least three tree species from the following list were planted at each site.

Black locust (BL)	*Robinia pseudoacacia* L.
Catalpa (CA)	*Catalpa speciosa* Warder
Cottonwood (CW)	*Populus deltoides* Bartr.
Honeylocust (HL)	*Gleditsia triacanthos* L.
Siberian elm (SE)	*Ulmus pumila* L.
Silver maple (SM)	*Acer saccharinum* L.

Plots were cultivated the first two growing seasons and mowed during the third.

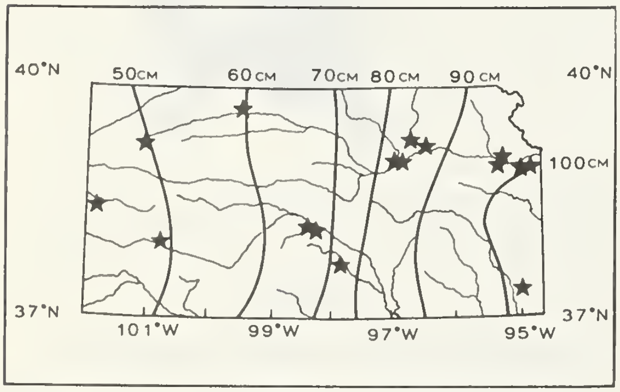

Figure 2.--Location of study areas and annual preciptation isobars in Kansas, U. S. A.

Measurements

Survival, diameter at 6 1/2 cm., and total tree height were taken starting in the second growing season. Single-tree yield curves were developed from additional trees planted in the area and constructed using the D^2H concept of Bowersox and Murphey, 1975. Area yields for each spacing were calculated from mean tree D^2H and survival by spacing for each species tested. Details of field procedures, calculations, economics and energy requirements are presented in separate papers (Geyer, 1981; Geyer and Melichar, 1982; Naughton and Geyer, 1982).

RESULTS & DISCUSSION

Above-ground biomass yield varied widely from eastern to western growing sites (Table 1). Annual growth ranged from a high of 13.7 to a low of 0.9 Mg/ha/yr on cultivated plots with an average tree spacing of 1.8 x 1.8 m (3700 trees/ha). The greatest yield was for black locust growing on deep alluvial silty clay loam soil at 97° W longitude. It performed best at all sites. Generalized growth curves are shown in Figure 3.

Table 1. Annual biomass productivity for all species combined[1] for cultivated plots after three growing seasons.

Site	Species	Longitude West			
		101°	98°	97°	95°
		(Mg/ha/yr)			
Silty upland	BL	4.0	---	7.2	6.1/7.2
	CW	---	---	---	2.7/6.1
	CA	---	---	---	---
	HL	1.1	---	3.4	---
	SE	4.3	---	5.8	3.1/6.3
	SM	---	---	---	3.1/8.3
Silty alluvial	BL	---	4.9	5.4/13.7	6.9
	CW	---	2.9	2.5/8.7	4.7
	CA	---	---	---	---
	HL	---	---	---	---
	SE	---	---	---	---
	SM	---	---	8.1	5.1
Sandy alluvial	BL	---	2.5	6.7	7.5
	CW	---	0.9	2.5	9.9
	CA	---	1.1	---	---
	SE	---	---	5.8	10.1
	SM	---	---	---	3.8
Number of sites		1	2	4	4

[1]Average spacing approximated 1.8 x 1.8m; approximately 3700 trees per ha.

Whole tree biomass growth rate increased with age and stand density. Cottonwood grown on silty soil in the east (95° W longitude) had an annual growth rate of 4.7 Mg/ha at three years which increased to 6.9 Mg/ha after six years. Trees planted at 1400 trees/ha had less than half the

yield (although more than twice the bole diameter) than those grown at the closest spacing (7000 trees /ha). As rotation age increased, the yield of the widest spaced trees approached 3/4 of that of trees at full stocking. Other species performed similarly to cottonwood, except in the fifth and sixth year. At that time, cottonwood growth decelerated at the two closest spacings, while growth of the other species did not.

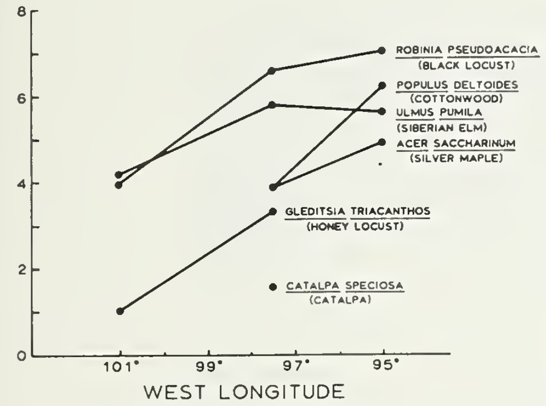

Figure 3.--Generalized biomass productivity curves after three growing seasons for cultivated soils in the Central Great Plains.

Four tree species have considerable potential for energy production in the Central Plains region of the U. S. A. In the east (95^{o} W longitude) where annual precipitation approaches 100 cm, black locust, cottonwood and silver maple grow well on silty soils, while cottonwood and Siberian elm are high producers on sandy alluvial soils. Further west at about 97^{o} W longitude and 75 cm precipitation, black locust grows best on silty soils with cottonwood, silver maple and Siberian elm having good potential; on sandy soil black locust and Siberian elm are best. In the far west (101^{o} W longitude) where precipitation is less than half that of the east, black locust and Siberian elm grow equally well on silty soils after three year's growth.

Both black locust and Siberian elm have been planted in each of the three east-west zones and may be compared at three years age on silty upland soils. Growth rate of both species, while the same in the drier west, increased in the eastern zones by 50% for locust and about 25% for Siberian elm, thus closely paralleling increased moisture patterns.

Black locust appears to perform best of all species tested in the geographic zones and sites under study, except where flooding occurs on alluvial sites. Results from three western plantings have not been reported, as they are less than the minimum age of three years. Siberian elm appears to be growing much better than black locust in these sandy dry areas mid-way through the third year. Initial survival of the locust is a problem on these droughty sites.

The yields attained in our study verify that with adequate weed control through cultivation, biomass productivity at the rates suggested by Ranney _et al_.,1982 (Figure 1) appear possible.

Optimum management techniques--herbicides for weed control, cutting age, and coppicing vigor--are yet to be determined. Energy and financial costs, while approximated in previous studies (Geyer and Melichar, 1982 and Naughton _et al_., 1980) need to be determined on a case study basis to ascertain the validity of short rotation energy fiber production.

Table 2. Relationship of biomass yield and age of cottonwood grown on silty soils in eastern Kansas.

Tree Density	Growing Seasons				
	2	3	4	5	6
#/ha	(% of full stocking)				
7000	100	100	100	100	100
4700	85	85	90	90	90
3200	65	65	75	75	85
2100	55	55	60	65	75
1400	45	45	55	60	70

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SCREENING OF EUCALYPTUS SPECIES FOR COPPICE PRODUCTIVITY[1/]

C. W. Comer and D. L. Rockwood[2/]

Abstract.--Eucalyptus grandis and E. robusta at 10,000 trees/ha initially had three times more stems per stool than at 1,600 trees/ha. By age one year the wide spacing averaged only one more stem per stool. Mean DBH for stems, in both spacings, was nearly equal at age one year. Total stem biomass produced was projected to be greater at the denser spacing. Eucalyptus amplifolia in northern Florida had excellent frost resilience and coppiced well, producing 25.2 dry mt/ha/yr in a two-year first rotation.

INTRODUCTION

Eucalypts have an opportunistic indeterminate growth habit, allowing growth anytime there is a conducive environment. Eucalyptus grandis and E. robusta grown in southern Florida (Palm Beach County) exhibit nearly continuous year-round growth. Moisture and nutrients are not considered limiting factors in the growth of coppice produced on muck soils.

Eucalyptus amplifolia in northern Florida (Alachua County), normally grows for a nine- to ten-month period from March through November, but can grow throughout the entire year if conditions are suitable.

This paper presents data collected from single 100-tree plots and provides insight and guidelines for future Eucalyptus coppice research in Florida.

1/ Paper presented at Southern Forest Biomass Working Group Workshop, Athens, Georgia, June 5-7, 1984. Funding for this research was provided by Oak Ridge National Laboratory through subcontract No. 9050 and the Gas Research Institute through a cooperative program with the Institute of Food and Agricultural Sciences of the University of Florida entitled "Methane from Biomass and Waste."

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MATERIALS AND METHODS

On muck soils near Belle Glade in southern Florida Eucalyptus grandis and E. robusta were planted in May 1980, in 100-tree square plots at two spacings, one by one meter (10,000 trees/ha) and 2.5 x 2.5 meters (1,600 trees/ha), and replicated three times for each spacing. The reps were harvested individually at periodic intervals to ascertain seasonal effects on coppicing and to test varying harvest rotations.

Heights of harvested coppice were measured using a metric-scale logger's tape and non-harvest heights were measured with a metric-scale telescoping measuring rod. All diameters at breast height were taken on standing coppice stems at 1.5 meters above groundline with a metric-scale diameter tape. The number of stems per stool was recorded as all stems which were at least one-half the diameter of the tallest stem for the stool.

In northern Florida, a single 100-tree plot spaced at one by one meter (10,000 trees/ha) of Eucalyptus amplifolia was planted in April 1981, near Gainesville. Weights were recorded using a platform scale and measured to the nearest one-tenth kilogram. Coppice biomass for each stool was divided into two component parts, stems with bark and branches with foliage.

RESULTS AND DISCUSSION

Eucalyptus grandis and Eucalyptus robusta

Coppicing ability varied by species and season of harvest. Eucalyptus robusta was found to coppice better than E. grandis on decayed organic (muck) soils in southern Florida. Harvests from mid-November through mid-March were

more successful in producing coppice growth than were those from warm weather months (Tables 1 and 2). Survival of live stools which produced coppice was found to be best for harvests done in January through mid-March (Tables 1 and 2).

Table 1.--Mean survival (%), height (m), and DBH (cm) for Eucalyptus grandis (EG) and Eucalyptus robusta (ER) coppice at one by one meter spacing for four harvest on muck soils in southern Florida.

Harvest Month / Species / Trait	Age (mo) 3	6	9	12	15	18	21
August 1981							
EG							
Survival	---	---	---	0	---	---	---
Height	---	---	---	---	---	---	---
DBH	---	---	---	---	---	---	---
ER							
Survival	---	---	---	3	---	---	---
Height	---	---	---	2.3	---	---	---
DBH	---	---	---	---	---	---	---
November 1982							
EG							
Survival	55	47	46	46	---	---	---
Height	---	2.0	4.7	5.7	---	---	---
DBH	---	0.8	2.5	2.8	---	---	---
ER							
Survival	53	47	46	46	---	---	---
Height	---	2.2	4.5	5.2	---	---	---
DBH	---	0.9	2.5	2.8	---	---	---
February 1982							
EG							
Survival	42	35	34	---	34	34	32
Height	1.1	3.2	4.6	---	5.7	8.5	9.8
DBH	---	---	3.1	---	5.1	6.0	7.0
ER							
Survival	72	71	69	---	69	68	66
Height	1.6	3.3	4.5	---	5.5	7.5	7.9
DBH	---	---	2.7	---	4.1	4.6	5.1
May 1982							
EG							
Survival	2	---	---	1	1	---	---
Height	1.3	---	---	---	6.8	---	---
DBH	---	---	---	---	6.2	---	---
ER							
Survival	14	---	---	12	12	---	---
Height	1.2	---	---	---	6.6	---	---
DBH	---	---	---	---	---	---	---

Coppice stems per stool were two to three times greater for the less densely planted stools compared to the 10,000 trees/ha planting. Six months after harvest date the number of stems per stool for the wider spacing was 17 to 22 stems per stool and the narrow spacing averaged seven stems per stool. By age 12 months a sharp decrease in the mean number of stems per stool was evident in the wider spacing. They then averaged five to seven stems/ stool compared to four to five stems/ stool for the denser planting (fig. 1).

Table 2.--Mean survival (%), height (m), and DBH (cm) for Eucalyptus grandis (EG) and Eucalyptus robusta (ER) coppice at 2.5 x 2.5 meter spacing for two harvests on muck soils in southern Florida.

Harvest Month / Species / Trait	Age (mo) 2	4	5	8	9	11	12	16
November 1982								
EG								
Survival	---	65	---	---	46	---	46	---
Height	---	---	---	---	4.7	---	5.0	---
DBH	---	---	---	---	3.1	---	---	---
ER								
Survival	---	44	---	---	41	---	41	---
Height	---	---	---	---	4.3	---	5.1	---
DBH	---	---	---	---	2.4	---	---	---
March 1983								
EG								
Survival	78	---	54	49	---	48	---	45
Height	0.4	---	3.2	4.3	---	4.7	---	7.1
DBH	---	---	1.8	3.0	---	---	---	5.9
ER								
Survival	83	---	76	70	---	68	---	68
Height	0.6	---	3.1	4.6	---	4.6	---	6.4
DBH	---	---	1.4	2.7	---	---	---	5.2

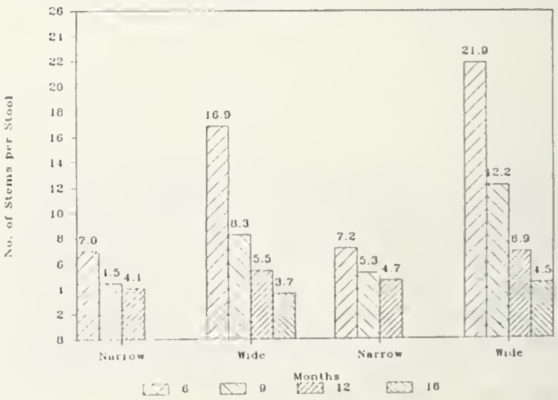

Figure 1.--Mean number of stems per stool for Eucalyptus grandis (left two clusters) and Eucalyptus robusta (right two clusters) at 10,000 trees/ha and 1,600 trees/ha on muck soils in southern Florida.

Height growth for the first year after planting was greater in the closely spaced stools. This would be somewhat expected because of competition from neighboring stools growth. Although a poor coppicer, Eucalyptus grandis coppice had greater height growth than E. robusta during the second growing season after harvest (Tables 1 and 2).

Diameter at breast height was uniform for both species at the narrower spacing throughout the first year after harvest. Then E. grandis increased more in mean DBH compared to E. robusta. Similarly E. grandis had a greater mean stem DBH than E. robusta at the wider spacing through 16 months following harvest (Tables 1 and 2).

Coppice stool productivity for the two species varied by species and spacing. The number of one-year-old stems extrapolated to be produced on a per hectare basis is four to five times greater for the one by one meter spacing than those for the 2.5 x 2.5 meter spacing for Eucalyptus robusta and three to four times greater for similar comparisons for E. grandis (Table 3).

Table 3.--Projected number of one-year-old coppice stems per hectare by season of harvest for Eucalyptus grandis (EG) and Eucalyptus robusta (ER) on muck soils in southern Florida.

Harvest Month / Species	Spacing	
	1 x 1 m	2.5 x 2.5 m
November		
EG	17,220	4,048
ER	21,620	4,526
February		
EG	13,940	4,224
ER	32,430	7,507

Eucalyptus amplifolia

Eucalyptus amplifolia coppiced well with 94 percent of the live stools coppicing after freezing to groundline after one season's growth following planting. Coppice growth following a January 1982 freeze was measured until it was killed by freezing in December 1983. New coppice, initiated during February 1984, was killed in a two-night freeze at the end of February. Since March, second-rotation coppice has been monitored and measured.

Growth of the first rotation coppice averaged 7.9 meters in height with a mean DBH of 8.2 centimeters after 23 months. Dry weight for two-year-old coppice was 25.2 mt/ha/yr with 17.7 mt of that weight produced in the stem component (Table 4).

This Eucalyptus species has shown remarkable resiliency to frost kill. Stool survivals of 94 and 99 percent, respectively, for first and second coppice rotations were recorded following two major freezes to groundline (Table 4).

CONCLUSIONS

Coppicing ability is an important aspect of Eucalyptus fuelwood production. The number of stems per stool, their size (height and DBH), and survival have significant impact on the usable biomass produced on a short rotation woody biomass plantation.

Our preliminary findings for E. grandis and E. robusta on muck soils in southern Florida indicate that one-year-old coppice production at 10,000 trees/ha is greater than at 1,600 trees/ha. These trends are continuing in the second growing season. The economics of planting, cultivation, and harvest costs need to be combined with these biological responses to determine operational methodology.

In northern Florida, frost tolerance of Eucalyptus is a necessity for biomass production on a commercial scale. Eucalyptus amplifolia has shown excellent frost resiliency and a high rate of coppice growth at the 10,000 trees/ha. Research on variability for frost hardiness within this species is underway.

Harvesting of E. amplifolia can be conducted from early November through late March, but because of the frequent chance of killing frosts from late December through February, it is advisable to carry out harvests in northern Florida during January and February to prevent set-back due to freezing of newly emerging coppice.

Table 4.--Coppice growth and productivity of Eucalyptus amplifolia in northern Florida.

Rotation	1st				2nd
Age (mo)	5	11	19	23	3
Trait					
Height (m)	2.08	4.46	6.32	7.89	1.31
DBH (cm)	0.89	2.95	7.56	8.22	---
Survival (%)	93.00	94.00	94.00	94.00	99.00
Dry Weight (mt/ha/yr)					
Bole	---	---	---	17.70	---
Branch	---	---	---	7.50	---
Total	---	---	---	25.20	---

SESSION III

Harvesting and Utilization of Forest Biomass

A. B. Curtis, Jr., Moderator

HARVESTING BIOMASS PLANTATIONS--EQUIPMENT DESIGN AND IMPACT ON PRODUCTIVITY[1]

HARRY G. GIBSON and PHILLIP E. POPE[2]

Abstract.--Short rotation intensive culture (SRIC) biomass plantations of black locust (Robinia pseudoacacia L.) and European black alder (Alnus glutinosa L.) were harvested after three growing seasons by sawing or guillotine shearing. Subplots were established to determine the influence of method of harvest, soil compaction and induced stump damage of rubber tired and metal tracked vehicles on coppice production. Method of harvest (sawing or shearing) had no significant influence on coppice dry matter production of individual stumps, however, shearing of the 1 x 1 and 0.5 x 1 meter spacing produced more dry matter from sprouts than shearing at other spacings or sawing at any spacing. Tracked vehicles caused more stump damage than rubber-tired vehicles for both species tested. Productivity of the stumps was inversely related to stump damage though productivity significantly declined only for stumps assessed as being "heavily" damaged. Succeeding passes of the pneumatic tired tractor over randomized subplots resulted in increased soil strength and density down to 15.2 cm. Compaction did not affect the number of sprouts produced at 0, 2, 6,, or 10 passes but did significantly affect (reduce) sprout height at 6 and 10 passes. Using an optimization technique OPTLIB, an analysis was made to determine parameters for the design of a SRIC biomass harvester. The results of this optimization analysis indicated a slow speed (1.17 kph) machine of eight foot width, 164 kw, weighing 10,536 kg could produce energy chips at a cost of $2.28 per green tonne.

INTRODUCTION

The realization that domestic sources of energy are necessary to replace or reduce the dependence on imported oil has slowly but surely increased throughout the United States since 1975. Agreement seems to have increased somewhat concerning the potential exploration of as many alternative production systems as possible. The diversity of such systems (solar, wind, biomass, etc.), both in size and type, will help to spread the risks of energy supply and promote continued success to valuable oil in the future. These alternatives should comply with reasonable demands for environmental protection and economic profitability.

Wood is the largest biomass energy resource in the United States and its importance as an alternate of supplemental fuel is dramatized by recent fossil fuel shortages. A report from the Office of Technology Assessment (1980) indicates woody biomass, in addition to its traditional uses, will play a major role in future energy production through gasification or conversion to liquid fuels. In the short run, most of the energy resource needs from biomass is expected to come from residues in conventional harvesting but an increase in the

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1 Paper presented at Sixth Annual Southern Forest Biomass Workshop, Athens, Georgia, June 5-7, 1984.

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intensity of forest management, including the establishment of biomass/silage plantations, may be essential to achieve the projected energy yield from wood while maintaining the supply of material to forest industries.

Numerous studies have been undertaken, and many completed, regarding practices, economics, and production of short-rotation, intensively cultured (SRIC) tree plantations (Pope and Gibson, 1984; P.C. Jones and S-Y. Shen, 1982; A.D. Vyas and S-Y. Shen, 1982). Information on technology to harvest SRIC tree plantations is more limited (Pope and Gibson, 1983) and, in general, discusses biomass harvester designs that are outgrowths of conventional timber harvesting machines.

Belanger (1979) and Machado (1981) note that the method of harvest can have a significant impact on the productivity of the remaining stump. Scientists have recognized the importance of "stump management" in sustained coppice productivity for some time. Research plantings are usually harvested manually during the dormant season and care is taken to maintain a 15 cm stump height, minimize disturbance of the root system, and make smooth stump cuts -- all of which minimizes the likelihood of stump fracture or splitting which reduces coppice productivity (Hansen and Baker, 1979; Belanger, 1979). When SRIC plantations have been harvested mechanically (Dawson et. al., 1976; Perala, 1979) there have been no data presented for stump damage and/or subsequent coppice productivity.

Some developments have been made towards harvesting low quality hardwoods through the use of a tracked harvester/chipper (Koch and Savage, 1980). This type of harvester was not designed for SRIC plantation use, however, and indications are that the weight and track carrier of this type of machine would seriously damage the root stock. In fact, the machine is promoted for site conversion where hardwood root stock mortality is beneficial. Scandinavian efforts toward SRIC biomass harvester developments are relatively new (Crafood, 1980) and are directed towards Scandinavian species and site conditions. Brazilian efforts toward mechanizing SRIC plantation harvesting have been minimal (Machado, 1981), mainly due to low labor costs and plentiful labor.

Presently, technology for mechanized harvesting of single and multiple stems of the size attainable in a 3-5 year rotation is lacking. Paramount in developing a harvesting system will be cost effectiveness, minimization of detrimental impacts on the site and assurance of survival and continued productivity of the stumps remaining after harvest. Productivity data are available for successive rotations of American sycamore (*Platanus occidentalis* L.) and eastern cottonwood (*Populus deltoides*, Bastr.) for root stocks of varying age but these plantations were harvested manually and care was taken not to damage the root stocks. Previous research indicates that conventional equipment is too costly, causes soil compaction and may injure the remaining stumps to the extent that biomass yields can be significantly reduced (Machado, 1981). The objectives of this study were to determine the influence of mechanical stem severing techniques on the coppice productivity of biomass plantations and to develop parameters for the design of a harvester for SRIC coppice biomass tree plantations. An assessment of soil compaction influence on coppice productivity was also an objective of the study.

PROCEDURES

Study Site

Short rotation intensive culture (SRIC) biomass plantations of black locust (*Robinia pseudoacacia* L.) and European black alder (*Alnus glutinosa* L.) were established at Martell Forest in the spring of 1979. Prior to planting, the site was characterized by soil type, slope, aspect, estimated tree productivity and soil nutrient status. One-year-old bareroot seedlings of each species were planted in pure stands equivalent to 5,000, 10,000 and 20,000 plants per hectare (ha), representing spacings of 2 x 1, 1 x 1 and 0.5 x 1 m, respectively. The study plots were limed and fertilized as specified in the study plan, and competing herbaceous and woody vegetation was controlled by cultivation. The experimental design for each tree species consisted of two fertilizer treatments (for another study reported on separately) randomly assigned over three blocks forming six main plots. Three spacings were randomly assigned to subplots within each main plot. Each subplot was 12 x 12 meters. The study was arranged in a randomized complete block design with three replications and analyses based on unequal sample size.

Harvesting Method Evaluation

After three growing seasons, alternate rows of the original 12 x 12 m net plots were harvested by sawing or guillotine shearing at a standard 15 cm stump height. Border rows, to be used for an assessment of the impact of soil compaction on coppice growth and rows allocated to determine the influence of vehicle track damage on coppice growth, were excluded from the measurement plots. In total, 90 m^2 of the original 144 m^2 was evaluated to assess the influence of harvesting technique on coppice productivity. The cut stumps were coded by the method of harvest, stump diameter, and stump condition. Stump condition was classified by the evenness of cut, the amount of compressed wood and the extent of bark damage (Table 1).

Fertilizer was applied to one-half of the harvested area to include both harvesting techniques. Coppice productivity was evaluated for each stem severing technique for four fertilizer treatments.

Table 1. Classification of stump damage caused by the method of harvesting sawing or guillotine shearing.
or guillotine shearing.

Component Evaluated	Method of Evaluation
Stem Diameter	Average of 3 diameter measurements were recorded. Point of measurement was 6 cm below the point of detachment.
Compression Wood	1 = no compression wood 2 = compression wood in > 0-25% of the exposed stump surface 3 = compression wood in 26-50% of the exposed stump surface 4 = compression wood in 51-75% of the exposed stump surface 5 = compression wood in 76-100% of the exposed stump surface
Cambial Tissue Injury	1 = no separation of cambial tissue from woody tissue 2 = 1-25% of the cambium separated from the woody tissue 3 = 26-50% of the cambium separated from the woody tissue 4 = 51-75% of the cambium separated from the woody tissue 5 = 76-100% of the cambium separated from the woody tissue

At time of planting, soil samples were collected from 24 locations, in each of the main plots.

Coppice productivity for all stumps was assessed by the number of sprouts per stump, and the height and diameter of the dominant stem. The coppice on 10 percent of the stumps was removed after the first growing season and total dry weight determined. Regression analysis was used to predict (estimate) the standing coppice biomass.

The study was arranged in a randomized complete block factorial design with 5 replications of each treatment. For each tree species, locust and alder, the factors are 3 spacing densities, 4 fertilizer treatments and 2 methods of harvesting. A total of 630 stems were harvested for each tree species. For each tree species, 45 trees were harvested by each stem severing technique on the 2 x 1 m plot, 90 trees by each technique on the 1 x 1 m plot and 180 trees on the 0.5 x 1 m plot. Border row trees served as a buffer and were not measured.

A two-wheel-drive, rubber-tired tractor, having a ground pressure of 16 psi, was driven between rows of alder and locust harvested by shearing or sawing to simulate the effect on the soil of harvesting equipment. Treatments included 0, 2, 6 or 10 passes over the soil. Compaction treatments were conducted when the soil moisture was approximately 15.5 percent. Based on a previous study (Gaultney, 1980), the potential for soil compaction is greatest in the range of 17 to 18 percent soil moisture for this Fincastle silt loam soil. Immediately following the compaction treatments, soil compaction was determined between rows (in the vehicle track) and within rows of stumps (not in the vehicle track). Compaction, as measured by a cone penetrometer, was taken at three depths, 0-7 cm, 9-15 cm and 27-33 cm with three replications for each sample depth.

Compaction and Stump Damage Evaluation

To measure the influence of compaction on stump productivity, data was collected on the number of sprouts per stump and height of the dominant sprout. The statistical design was a completely randomized design with 3 replications for each compaction treatment with 10 observations per replication. Data was analyzed by analysis of variance and mean values for significant variables were separated by Duncan's new multiple range test. Damage to stumps may be caused by the tires or tracks of the carrier. To assess this damage and its impact on stump productivity, designated rows of alder and locust harvested by each of the stem severing methods were subjected to four passes by either a tracked vehicle or a rubber-tired tractor. Damage was assessed immediately and placed into one of four categories (Table 2). The number of sprouts per stump and the height of the dominant stem of each stump were used to estimate the influence of stump damage on productivity. Data were analyzed by analysis of variance and means of signficant treatments were separated by Duncan's new multiple range test.

Table 2. Rating scheme for damage inflicted on harvested stumps caused by rubber-tired or track vehicles.

Code	Type of Damage
0	No Damage
1	Slight Damage (minimal damage to stump)
2	Moderate Damage (up to 50% of the bark loosened or removed, stump moveable)
3	Heavy Damage (more than 50% of the bark loosened or removed, stump split, and dislodged and/or roots uplifted.

To saw the trees a standard chainsaw was used. Shearing required construction of a prototype shear that would sever the tree (Figure 1). Rows of trees within a plot being harvested by the same method, chainsaw or shear, were cut at approximately six inches (15 cm) above ground level (Figure 2). Fresh weights were determined for all trees within a plot being harvested by the same method.

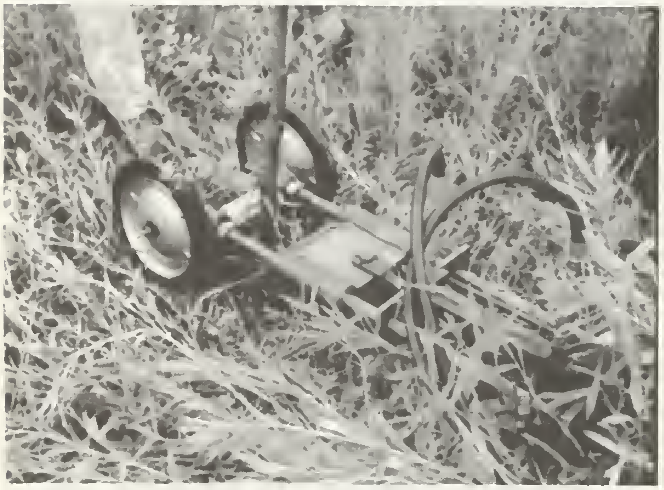

Figure 1. Hydraulic shear used to sever stems 15 cm above the ground.

Stumps in selected rows were scraped or run over with a small, steel tracked, dozer. A pass down the row and back was used to simulate movement of the machine in a harvesting operation. Similarly, stumps in other rows were scraped or run over with the rubber tires of a medium-sized Ford tractor. Again, a pass down the row and back was used to simulate movement during harvest.

Figure 2. Stump from tree that has been sheared at 15 cm height.

Harvester Simulation

Seven variables were selected as representing the important parameters that govern the performance of a self-propelled woody biomass harvester. These variables are: speed, width, weight, price, power, tractive effort, and hours of operation per year. An optimizing simulation model was developed for a woody biomass harvester using successive linearization as per the method used by Griffith and Stewart in their OPTLIB model. This simulator was used to determine optimum general harvester specifications.

RESULTS

Chainsaw Versus Shearing

Method of harvest had no significant influence on coppice dry matter production of individual stumps or the stem:foliage weight ratio which averaged 0.54 kg per stump and 1.58, respectively. However, total coppice dry matter produced per stump tended to be greater for the sheared stumps at the 1 x 1 (0.53 vs 0.32) and 0.5 x 1 m (0.47 vs 0.36) spacings. A summary of the influence of chainsawing and shearing on growth parameters of alder coppice is presented in Table 3.

Table 3. Summary of the influence method of harvest on the growth parameters of coppice for European black alder.

Spacing 0.5 x 1m

Variable	Method of Harvesting: Chainsaw	Shear
Sprout Height (cm)	127.4	168.2
Number of Sprouts	14.0	14.3
Dry Wt (Stem) kg	0.179	0.273
Dry Wt (Fol) kg	0.098	0.127
Total (Dry Wt) kg	0.277	0.400
Stem/Foliage	1.82	2.14

Spacing 1 x 1 m

Variable	Method of Harvesting: Chainsaw	Shear
Sprout Height (cm)	145	135
Number of Sprouts	16.1	18.4
Dry Wt (Stem) kg	0.306	0.236
Dry Wt (Fol) kg	0.169	0.143
Total (Dry Wt) kg	0.475	0.379
Stem/Foliage	1.81	1.65

Spacing 2 x 1 m

Variable	Method of Harvesting: Chainsaw	Shear
Sprout Height (cm)	111	116
Number of Sprouts	18	20
Dry Wt (Stem) kg	0.18	0.18
Dry Wt (Fol) kg	0.15	0.12
Total (Dry Wt) kg	0.33	0.30
Stem/Foliage	1.20	1.50

Injuries from Tractors

Tracked vehicles caused more stump injuries than rubber-tired vehicles for both tree species tested (Table 4). Black locust tended to incur more damage than alder for each of the treatments tested but a X^2 goodness of fit indicated no significant difference. The trend for more stump injury in locust may be a result of an inherently lower wood moisture content which can cause the bark and stemwood to split under stress. The alder stumps were not as easily dislodged as the locust but did experience more separation of the cambial tissue from the wood.

Productivity of the stumps were inversely related to stump damage though productivity significantly declined only for stumps assessed as being "heavily damaged" (Table 5). The productivity of a stump within a damage category was not influenced by the method used to inflict the damage. Consequently, productivity within a particular damage category is averaged for tracks and rubber tires. The injury inflicted on the stumps resulted from four passes with a metal tracked or rubber-tired vehicle. It is unlikely that such deliberate and extensive damage will occur in an operational mode. However, it is apparent from the data that damage must be in the "moderate" to "heavy" category before a reduction in stump productivity is observed.

Soil Compaction

Compaction results from cone index readings, Figures 3 and 4, and bulk density measurements, Figure 5, give general indications that soil strength (cone index) and soil density (bulk density) increased with the number of passes made by the agricultural tractor tire. Different soil conditions existed initially at different depths on Plot 6 (Figure 3) as the cone index readings dropped from 2 inches (5.1 cm) down to 6 inches (15.25 cm) but a higher reading was found at the 12 inch (30.5 cm) depth. The soil condition at the 12 inch depth is attributed to agricultural plowing of the soil in prior years that developed a compressed pan of soil at that depth.

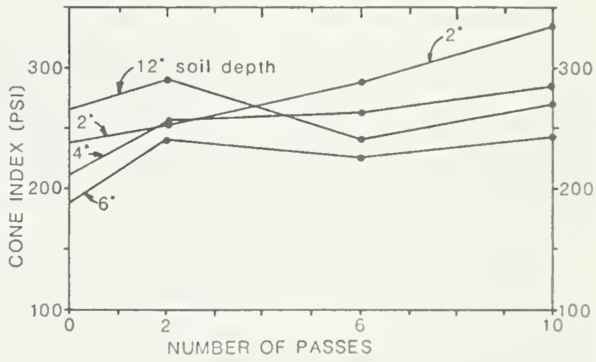

Figure 3. Soil compaction as indicated by cone index values for multiple passes over the soil by an agricultural tractor (Plot 6).

Table 4. Influence of metal-tracked or rubber-tired vehicles on the damage inflicted on 15 cm stumps of locust and alder. Values represent the frequency (%) that a particular level of damage is present.

Classification	Damage Locust		Alder	
None	--	--	10	15
Slight	20	20	50	55
Moderate	30	35	25	20
Heavy	50	45	15	10

Table 5. Influence of stump damage on the productivity of 1 year-old coppice of locust and alder.

Damage Classification	Locust Stem Ht. (cm)	Locust Number of Sprouts/Stump	Alder Stem Ht. (cm)	Alder Number of Sprouts/Stump
None	146a[1]	10a	157a	15a
Slight	143a	7a	161a	16a
Moderate	107ab	9a	117ab	14a
Heavy	49b	4b	69b	8b

[1]Values for a particular tree species and productivity variable not followed by the same letter are significantly different by Duncan's new multiple range test ($\alpha = 0.05$).

On Plot 6 all soil depths showed an increase in penetration resistance as recorded by the cone penetrometer with increased passes of the agricultural tractor over the soil with two exceptions: At the 6 inch depth and 6 passes and at the 12 inch depth and 6 and 10 passes.

The soil in Plot 7 was of different physical condition than Plot 6 as evidenced by lower penetration resistance. Initial cone index readings were lower, ranging from 125 to 144 psi for the 2, 4, and 6 inch depths as compared to 190 to 268 psi for the same depths in Plot 6. With succeeding passes over the soil by the agricultural tractor tire, cone index readings increased (Figure 4) as they did in the previous area, Plot 6. The 12 inch depth again had higher readings indicating a hard pan.

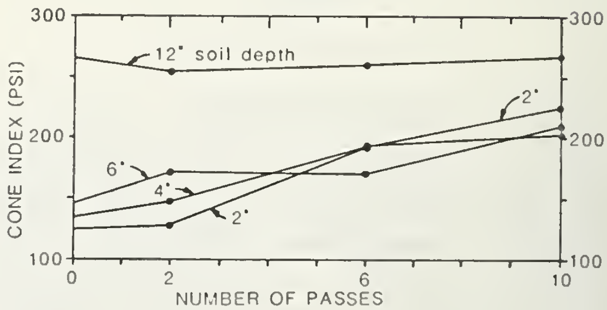

Figure 4. Soil compaction as indicated by cone index values for multiple passes (Plot 7).

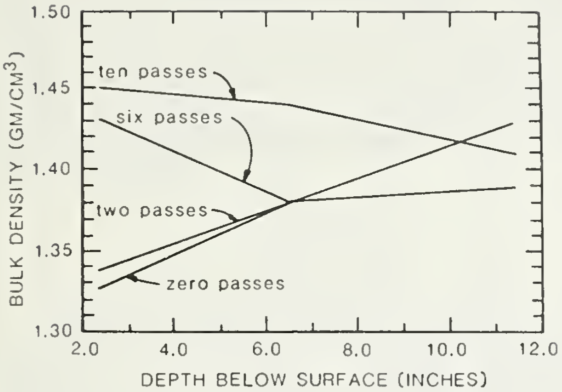

Figure 5. Effect of machine passes on bulk density of the soil.

Soil bulk densities, Figure 5, showed the general trend of soil compaction with increasing passes.

Increased soil compaction from multiple passes of the agricultural tractor over the plantation soil is reflected in reduced height of one year old coppice (Table 6). Zero and two passes showed no significant difference in number of sprouts or sprout height, nor did six and ten passes. However, six and ten pass sprout height was less when compared to zero and two pass growth. In effect, compaction did reduce sprout height after more than two passes. From a design standpoint, production will be reduced after more than two passes, hence ground pressure from the harvester tractive component (tires or tracks) and repeated travel over the site should be minimized. Put another way, the contact patch with the ground of tires or tracks should be maximized up to the point of incurring damage from limited maneuverability due to the tractive component width. Tracks, due to their larger contact patch, would be the logical choice <u>if only compaction</u> were considered.

Harvester Simulation Results

The optimization model OPTLIB was used with selected harvester operating variables to determine different combinations of design parameters for such a machine.

Variables used:
- X1 = Harvester Speed
- X2 = Width
- X3 = Weight
- X4 = Price
- X5 = Horsepower
- X6 = Tractive Effort
- X7 = Hours of Operation (annual)

The overall strategy is to produce wood chips at the lowest possible cost. To do this a machine must be matched to the optimum operating conditions. With the seven variables defined an equation describing cost of producing chips with a harvester is formulated. This equation is:

MINIMIZE: Machine Cost Per Year/Tons Harvested Per Year

This basic equation results in $/ton and can be rewritten in terms of the variables giving the objective function to be optimized.

OBJECTIVE FUNCTION = MIN:
(0.11483*X4+0.015*X5*X7+3.373*X7)
÷ (X1(X2*X7))

Using the relationships described above the objective function is subject to the following constraints:

a. WEIGHT = 109.6 * HP

b. HP = .00267*TE*SPEED+35.1647*SPEED*WIDTH +.606097*WIDTH

c. TE = 0.22 #WEIGHT

d. PRICE = 250. #HP

Initially five starting points were determined to make sure the program would converge on the global optimum if there was one. The five points picked were scattered throughout the feasible regions defined for the objective function.

Initial runs indicated there were several local optima and the algorithm converged differently depending on the initial starting point. Although several optima were found, obvious trends in SPEED and WIDTH were discovered. Slow speeds resulted in the optimum solution throughout all horsepower ranges. Similarly wide machine widths were present in all results. This indicates the best machine should incorporate a cutting head that is as wide as possible and be designed to harvest at a slow speed near one mile per hour.

Other parameters like weight, price and tractive effort increased with horsepower as their defining equations dictate. Hours operating per year were the same for all runs indicating a minimum for hours in the objective function. Horsepower at the optimum differed depending on input conditions indicating the objective function contains many optimum points which the algorithm converged on depending on initial proximity to the point. The most important result is the net cost per ton to produce wood chips. A trend of decreasing production cost with increasing machine size is present and was somewhat expected since this is

Table 6. Effect of soil compaction(number of passes) on the productivity (height and number of sprouts) of lyear old coppice of black locust and European black alder.

	Number of Passes							
	0		2		6		10	
	Locust	Alder	Locust	Alder	Locust	Alder	Locust	Alder
Height (cm)	137a[+]	151a	130a	149a	87b	101b	56b	91b
Number of Sprouts	9a	15a	7a	15a	10a	12a	8a	11a

[+]Values for a particular characteristic for each species not followed by the same letter are significantly different by Duncan's new multiple range test ($\alpha = 0.05$).

NOTE: There was not an influence of harvesting as a main or interactive variable.

a common phenomena in agricultural operations. The initial results indicated a machine width much too wide to travel on a conventional highway so the upper bound on width was lowered to eight feet.

Results of the second analysis were identical to the first except in variables SPEED and WIDTH. At the limited width of eight feet in this run, the speed was increased to satisfy the constraints and the same horsepowers were found to be optimum even at these different speed and width combinations. The net result of imposing narrower width restrictions than found optimum was a higher cost per ton of wood chips produced.

Investigation of possible tire combination to work with the above machine parameters produced a limitation on machine weight below the initial estimate. Combining this restriction with tire performance charts the maximum weight of an eight foot wide harvester must be limited to 26,600 lbs.

The program converged on the same solution as before instead of finding another feasible local optimum between 220 HP and 254 HP. This indicates there is no other optimum solution between these values. The selection of the following design parameters is suggested based on this analysis.

1. SPEED: .73 mph
2. WIDTH: 8.0 feet
3. WEIGHT: 24189 lbs.
4. PRICE: 55176 dollars
5. H.P.: 220
6. TRACTIVE EFFORT: 5321 lbs.
7. HOURS: 1167 operate per year
8. PREDICTED COST: 2.07 $/TON

The alternatives considered in this study - tracks vs. wheels, saws vs. shears, and combinations of weight, horsepower, and speed - result in general specifications for a harvester for short rotation, intensively cultured (SRIC) tree species for energy plantations. While these specifications should be used with caution, they do give indicators for design of a harvester to be used on SRIC energy plantations composed of alder or black locust, planted on one meter spacings, in silt loam soils in mid-western locations. General specifications for such a harvester are given in Table 7.

Table 7. General Harvester Specifications.

Severing Method:	Saws or Shears
Vehicle Traction Method:	Pneumatic Tires
Tire Section Width:	24.5 in. (62 cm)
Tire Design Diameter:	71.0 in. (180 cm)
Vehicle Operating Speed:	0.73 mph (1.17 kph)
Harvesting Width:	8 ft. (2.4 m)
Machine Weight:	24,189 lbs. (10,536 kg)
Machine Power:	220 Hp (164 kw)

For a harvester with a cost of $55,176.00, this unit would produce energy wood at a cost of $2.07 per ton ($2.28 per tonne). Severing method could be either by chainsaw or by shear though a sawing method would be more conclusive to continuous motion of the machine through the plantation (shearing would necessitate stopping the machine or a complex relative motion shearing head design).

CONCLUSIONS

Method of harvest (sawing or shearing) had no significant influence on coppice dry matter production of individual stumps, however, shearing of the 1 x 1 and 0.5 x 1 meter spacing produced more dry matter from sprouts than shearing at other spacings or sawing at any spacing.

Tracked vehicles caused more stump damage than rubber-tired vehicles for both species tested. Productivity of the stumps was inversely related to stump damage though productivity significantly declined only for stumps assessed as being "heavily" damaged.

Succeeding passes of the pneumatic tired tractor over randomized subplots resulted in increased soil strength and density down to 15.2 cm. Compaction did not effect the number of sprouts produced at 0, 2, 6, or 10 passes but did significantly affect (reduce) sprout height at 6 and 10 passes.

Using an optimization technique OPTLIB, an analysis was made to determine parameters for the design of a SRIC biomass harvester. The results of this optimization analysis gave the following design parameters:

Speed:	0.73 mph (1.17 kph)
Width:	8.0 feet (2.4 m)
Weight:	24,189 lbs. (10,536 kg)
Price:	55,176 dollars
Horsepower:	220 (164 kw)
Tractive Effort:	5.321 lbf (23,668 N)
Operating Hours:	1,167 per annum
Predicted Cost:	2.07 $/green ton (2.28 $/tonne)

The analysis showed that the best tractive means was by pneumatic tires, though this is a compromise.

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Alternate Biomass Harvesting Systems Using Conventional Equipment[1/]

Bryce J. Stokes, William F. Watson, and I. Winston Savelle[2/]

Abstract.--Three harvesting methods were field tested in two stand types. Costs and stand utilization rates were developed for a conventional harvesting system, without energy wood recovery; a two-pass roundwood and energy wood system; and a one-pass system that harvests roundwood and energy wood. The systems harvested 20-acre test blocks in two pine pulpwood plantations and in a natural pine sawtimber stand. The one-pass method resulted in the least cost and better utilization of biomass residue.

INTRODUCTION

Most of the conventional harvesting operations in use today leave usable biomass to be windrowed and burned. Typical management strategy in the South is to clearcut mature stands, do mechanical site preparation, and replant the site. Clearcutting removes wood that can then be delivered to market at a profit. In most cases, the pine component of the the stand will be the most completely utilized. The tops and stems, some up to 6 inches dbh, are left to be disposed of during the subsequent site preparation operations. Sawlogs are usually the only hardwood component harvested from the stand--limby tops and hardwood stems less than 12 inches dbh are left on the clear-cut area.

It is not economical with conventional systems to obtain complete recovery of biomass, but they do have a great potential to improve utilization of this biomass. Feller bunchers have an accumulating ability that make it possible for them to efficiently harvest small stems.

Portable chippers have revolutionized the utilization of the entire tree. Young (1980) reported that with portable chipping more and more use has been made of tops for energy fiber. Chippers also increase utilization of defective and small trees.

This study was proposed to identify opportunities for reducing site preparation cost by more intensive utilization of residuals when harvesting with conventional operations. The study was accomplished in two phases. One phase was designed to quantify the harvesting costs associated with reducing residue during harvest. The second phase dealt with assessing costs for various site preparation methods and various levels of harvesting residue. In addition, site characteristics were determined before and after each phase to be sure that the particular strategies do not cause the site to deteriorate any more than other strategies studied. This paper reports results from the harvesting phase of the study.

Three harvesting methods were evaluated in two stand types; one was a pine pulpwood plantation and the other a pine sawtimber natural stand. The study was designed so that each harvesting method was studied on two 20-acre blocks for each stand type. Harvesting methods tested were (1) conventional--harvest all roundwood, (2) two-pass--a first phase to harvest energy wood and a second phase to conventionally harvest fiber and logs, and (3) one-pass --harvest all products simultaneously. Because of wet ground conditions, the harvesting tests were not repeated for the natural stand.

DATA COLLECTION

Three tracts were selected for the tests. Tracts I and II were 22-year-old slash pine plantations that were being clearcut for pulpwood. Both were in south Alabama but in different

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locations. The third tract was a natural slash--loblolly pine stand in south Mississippi. In the natural stand the larger, mature pines were approximately 45 years old. The understory in the natural stand consisted of pine and hardwood. Each tract was divided into three harvesting blocks that were 660 ft wide and 1,320 ft deep. The 20-acre blocks were the same configuration to maintain average skidding distances among the harvesting methods.

A cruise was conducted to determine the standing inventory of each block. Fixed radius 1/10-acre plots were established to measure trees larger than the 3-inch dbh class. In the center of these plots, a 1/200-acre fixed radius subplot was taken to determine the standing woody biomass for all trees in the 1 to 3-inch dbh classes. Destructive sampling was used on the 1/200-acre plots and the total green weight was recorded for each tree. All heights were measured in the subplots and sampled in the plots.

After the block perimeters were established and the stand information obtained, each block was harvested. Harvesting took place from June to October. Servis recorders were mounted on each machine. Recorder disks were collected daily to obtain the number of productive hours each machine operated on each block. A monitor maintained a record of crew hours for each block. All haul trucks were weighed at the mill to obtain the amount of harvested material by product type.

HARVESTING METHODS

Conventional

All pine trees 6 inches or greater in dbh were harvested. Hardwood trees at least 12 inches in dbh were also harvested. The harvesting system in the plantations consisted of two feller bunchers and three grapple skidders. A skidder with a directional shear was used to fell and skid trees in the natural stand. Chainsaws were used to fell trees that were too large for the directional shear. Delimbing and topping were completed by chainsaws in the stand or at the deck after the trees had been processed through an iron gate. The tree-length material was skidded to the deck where a hydraulic loader was used to load the tree-length pulpwood and sawlogs. Since this was a conventional harvesting system, there was no energy wood recovered. No hardwood pulpwood was recovered either.

One-Pass

For all tracts, three feller bunchers and two grapple skidders were used in the harvesting system. The natural stand also had the skidder with a directional shear for felling and skidding. The feller bunchers separated the trees into piles of energy wood or roundwood. All pine less than 6 inches dbh and hardwood less than 12 inches dbh in the natural stand were put in energy wood piles.

The energy wood was skidded directly to the chipper. Roundwood was skidded full tree to the deck where two chainsaw operators bucked the tops off to nominal merchantable limits. The bucking point was at the lowest live limb in trees from plantations and at a 4 to 6-inch top near the base of the crown in trees from the natural stand. The chipper grapple was used to move the tops and feed them. All the roundwood was loaded tree length.

Two-Pass

Three feller bunchers and two grapple skidders composed the harvesting system in all three blocks for the first pass to remove the energy wood. The energy wood was cut first to utilize wood that would otherwise be destroyed if the merchantable wood was harvested first. This meant that the feller buncher operators had to carefully maneuver around the merchantable trees. The trees were skidded directly to the chipper producing a clean stand, ready for the second pass.

After the energy wood had been harvested, a second operation removed the roundwood. The second-pass system utilized two feller bunchers and three grapple skidders in the plantation blocks. In the natural stand, the skidder with directional shear did most of the felling and all of the skidding. Chainsaws were used to fell trees too large for the shear and to delimb and top the roundwood in the natural stand. The iron gate was used for delimbing in the plantations.

RESULTS

A summary of the total standing biomass is shown in Table 1. Total tree weight equations were developed during a hardwood study done by Franchi, et al (1984). These equations and equations for pines (Reams, et al, 1982) were used to determine the total wood biomass for each block.

In tract I, the pulpwood (trees greater than 5.5 inches dbh) accounted for 67 percent of the total standing woody biomass. Tract II, the second plantation stand, had 73 percent in pulpwood. The difference between the two plantation stands was that tract I had more energy wood. In the natural stand, about 58 percent of the total standing biomass was pulpwood and sawlogs.

A careful examination of the harvested tonnage (Table 2) gives some insight into the various harvesting methods. Not as much roundwood was recovered from the stand for the one-pass method as with the other harvesting methods. One reason for the reduction in the roundwood in this system is that the tops being sent to the chipper included more of the bole to facilitate feeding the chipper.

As expected, utilization was higher for the one-pass than the other harvesting methods. This was a result of chipping the limbs and tops of the merchantable roundwood in addition to the small diameter trees. Utilization was also generally better in the plantation stands than in the natural stand for the methods tested.

Machine and labor cost estimates were used instead of actual costs (Table 3). The machine rates were developed for each specific machine using new replacement costs. Labor rates, including fringe benefits, were assumed. These rates were used to develop cost estimates per green-ton-to-roadside for the different harvesting methods. However, harvesting costs (Table 4) do not include service equipment, crew transportation, and hauling costs.

The one-pass was the most economical alternative even though chipping costs associated with this method were higher than the two-pass. This is directly related to chipper utilization. During the process of removing the tops at the deck from the merchantable trees, the interaction of the skidders, buckers, loader, and chipper caused delays and affected chipper production. More refinement in the harvesting system components and methods might eliminate some delays and decrease chipping costs. The ratio of products going to the deck also affected balanced production of the system. This may restrict the one-pass effectiveness in several stand types because low utilization of the chipper results in high-cost energy wood.

In the natural stand, the conventional method was the lowest cost option because of tree size. Even though the harvesting costs were low, there was no energy wood harvested and the land manager had a large slash problem to handle.

CONCLUSIONS

In general, conventional equipment and systems can be used to economically harvest more of the total woody biomass. The one-pass method resulted in the best utilization of and lowest costs among the harvesting alternatives considered in these stand types. More information is needed on harvesting the energy wood components for different stands and different stand compositions. Studies are needed to identify the optimal equipment mix and to refine the operation of the one-pass system. Also, the system should be evaluated over a range of stand conditions.

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Table 1.--Cruise summary of plantation and natural stands

Tract	Block	Components (inches) All 1-3	Pine 4-5	Pine ≥6	Hardwood 4-11	Hardwood ≥12	Total
		green tons per acre					
I (plantation)	1	14.2	4.9	50.4	9.9	-	79.4
	2	5.4	7.9	68.8	3.0	-	85.1
	3	20.8	10.8	59.3	9.6	-	100.5
	Average	13.5	7.9	59.5	7.5	-	88.3
II (plantation)	1	6.9	12.7	63.9	9.3	-	92.1
	2	7.4	8.3	61.9	7.3	-	84.8
	3	7.0	9.9	57.9	7.5	-	82.0
	Average	7.1	10.3	61.2	8.0	-	86.3
III (natural)	1	25.0	7.0	62.7	11.9	0.0	106.6
	2	22.5	2.5	58.1	22.0	3.3	108.4
	3	23.4	1.2	40.4	16.2	19.8	101.0
	Average	23.6	3.6	53.7	16.7	7.7	105.3

Table 2.--Harvested green tons per acre

Tract	Block	Harvest Description	Energy Wood	Roundwood	Total	Percent[1/]
			----green tons per acre------			
I	1	Conventional	--	40.7	40.7	51.3
(plantation)	2	One-Pass	34.4	43.3	77.7	91.3
	3	Two-Pass	30.3	48.0	78.3	77.9
II	1	Conventional	--	60.6	60.6	65.8
(plantation)	2	One-Pass	40.6	35.0	75.6	89.2
	3	Two-Pass	29.1	41.0	70.2	85.6
III	1	Conventional	--	42.5	42.5	39.9
(natural)	2	One-Pass	35.0	45.9	80.9	74.6
	3	Two-Pass	19.8	46.0	65.4	64.8

[1/]Percent of cruised total-standing biomass.

Table 3.--Machine and labor rates

Function	Machine	Machine Rate per operating hour	Labor Rate[1/] per scheduled hour
		----------------dollars----------------	
Felling	Feller buncher[2/]	35.40 - 55.82	10.00
Trimming	Chainsaws	4.50	8.00
Skidding	Skidders[3/]	33.12 - 38.11	10.00
Chipping	22-inch Chipper	83.03	10.00
Loading	Knuckle-boom	21.95	10.00

[1/] Includes fringe benefits.
[2/] Cost depends on feller buncher.
[3/] Cost depends on which rubber-tired skidder used.

Table 4.--Harvesting costs by method[1/]

Tract	Conventional	One-Pass Energy wood	One-Pass Roundwood	One-Pass Combined	Two-Pass Energy wood	Two-Pass Roundwood	Two-Pass Combined
	-------------------------Dollars per green ton----------------------------						
I (plantation)	10.10	8.35	6.45	7.39	12.70	6.60	8.97
II (plantation)	9.88	8.30	7.11	7.75	12.11	6.61	8.89
Average	9.99	8.32	6.78	7.57	12.41	6.60	8.93
III (natural)	6.25	10.15	5.84	7.70	13.34	4.62	8.71

[1/]Costs are per green ton to roadside and do not include service equipment, crew transportation, or supervision.

THE ECONOMIC IMPORTANCE OF WOOD ENERGY IN GEORGIA[1/]

J. FRED ALLEN[2/]

Abstract.--While the 1979 oil embargo seems distant, it still lingers in our minds and the effect that it had can still be seen today. While the effect at first was adversely felt, the problem has developed into a positive factor. Georgia, in an attempt to reduce their dependency on imported fuels began promoting our abundant wood resource as a viable alternative. The direct and indirect economical benefits associated with the conversion to wood energy has resulted in an annual savings in excess of a half billion dollars. In addition, a ''home grown'' fuel is being used as well as additional jobs created in the market.

INTRODUCTION

The 1979 oil embargo resulted in many homeowners, industries, and institutions searching for an alternate energy source primarily as a means of survival. Wood, which once played a major role in providing energy for this country again emerged to play a vital role in reducing costs and dependency upon imported fuels.

Georgia has 24 million acres of commercial forest land within its boundaries with 64 percent of the land belonging to the non-industrial private landowner. Forestry in Georgia is the number one industry with an annual contribution to the economy exceeding 6.6 billion dollars.

Because of the abundance of the wood resources and residue generated by local industries, the wood energy program was implemented to promote the utilization of wood as an alternate energy source. As with any program, goals must be set to determine the effectiveness of the program. Some of the anticipated goals are:

1. To develop a new product. Expand the use of energy wood outside the forest industry.

2. To increase employment somewhere in the market as a result of new equipment, wood usage, harvesting, etc.

3. To have a net savings for the end user.

4. To reduce the state's dependency on imported fossil fuels.

5. To utilize the opportunity to upgrade the existing forest stands through timber stand imporvement (TSI) or harvesting of poor quality stands to meet the future demands.

RESIDENTIAL IMPACT

The energy crisis effected most of us through our home utility bills because we felt the direct impact that it had upon our lives. In keeping with the American spirit, many individuals converted to an old form of heat to meet their requirements--the use of wood and the wood stove. In 1981 a survey conducted for the Commission indicated that approximately 675,000 homes in Georgia were using wood for heat in various wood burning appliances. Thirty-five percent of those surveyed were using wood to provide at least 50 percent of their heating requirements. This represented a 30 percent increase from the 1979 survey and reflected that approximately 20 percent of the homes surveyed plan to install some type of wood burning appliance in the near future. This increase in installation would represent an additional 400,000 homes to be heated with wood.

During the 1981 heating season, approximately 1.7 million cords of firewood were utilized by homeowners. This is equivalent to roughly 20 percent of the wood used in the state's pulp and paper industry, which Georgia leads the nation in production of pulp and paper. Moreover, 82 percent of this wood was cut by the homeowner from

1/ Paper presented at Sixth Annual Southern Forest Biomass Workshop, Athens, Georgia, June 5-7, 1984.

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his own land, national forests, friends or landowners who chose to sell firewood from their land. The remaining 18 percent was purchased from one of the various firewood producers throughout the state.

The total value of firewood purchased, as well as the implied value cut by the user, amounted to 135.5 million dollars. If the current trend continues, it should be anticipated that an additional 1 million cords of firewood will be needed to meet the demand.

A current trend is being set in the firewood industry. The days of chainsaw and pickup truck still exist and will continue, but the market is being infiltrated by modern mechanization which is capable of producing large quantities of wood in a relative short period of time. Today there are 6 producers in the state with a capacity of over 750 cords per year and with 1 producing in excess of 1,500 cords annually.

PRIVATE SECTOR

The forest products industry is no doubt the largest user of wood for energy. A 1981 survey indicated that the forest products industry utilized 8.5 million tons of wood as fuel as well as an undertermined amount of quantities of black pulping liquor. In addition, those industries surveyed indicated the possibility of expanding their total burning capacity in excess of 650,000 tons per year.

Wood as an energy source to the forest products industry offers an opportunity to reduce their annual fuel cost as well as an opportunity to eliminate a waste product without additional cost involved. At present, approximately 3 percent of the forest products residue generated is available for use. While the remainder--97 percent--is being utilized in other secondary products, fuel included, the use of a residue can change and should change as price dictates for fuel.

Other industries outside the forest products industry have benefited from the conversion to wood as an energy source. The 1981 survey indicated that approximately 300,000 tons of wood fuel was used by the non-forestry industries in the state, resulting in a savings of some 13 million dollars annually.

PUBLIC SECTOR

In promoting Georgia's wood energy program, the Commission was instrumental in installing wood-fired systems into 11 state facilities, one of which was the gasification project in Rome. This past heating season, the gasifier showed a 9 percent savings over conventional fossil fuels. But, since January 1984, the engineer at the hospital estimates that the system has been operational at least 50 percent of the time. It has already been shown that for every 24-hour period that the system is on line that $1,000 is saved by using wood over oil.

Central State Hospital is scheduled for completion in January 1985 and will be the largest state facility with a wood-fired heating system. It is estimated to burn 70,000 tons of wood chips annually with an estimated annual savings of $800,000, and a payback period of 3.1 years.

Three state correctional institutions have been converted over to wood as their energy source. While Georgia Industrial Institute, the largest of the facilities, did not operate the entire heating season, the combined installations resulted in an average savings of 40 percent through conversion to wood.

Five schools in the state are being heated with wood, averaging 24 percent savings through the use of wood. Franklin County High School converted from electricity at $23 MMBTU to wood at $2 per MMBTU.

The Forestry Commission's central facility in Macon showed a 56 percent savings over conventional fuels through its conversion to wood heat. In addition to the conversion, added benefits resulted in an agreement with U. S. Forest Service and the Commission in which the Commission sold heat to Forest Service facilities on the compound.

The state facilities that were on line last year resulted in a total savings of 22 percent for the taxpayers of Georgia. This savings is direct fuel savings and does not take into consideration additional maintenance costs or additional electrical costs that may have been incurred. All systems were assumed to be operating at 100 percent efficiency as well as the fuels burning at the same efficiency. The wood used in the state facilities replaced an estimated 10,273 barrels of oil, and it should be noted that the major system, Central State Hospital, will be coming on line in 1985 and the next largest system did not operate the entire heating season. It has been estimated that when all the state facilities are on line they will utilize 120,000 tons of wood annually at an estimated savings of 1.4 million dollars. This makes for an excellent payback on the investment the state has put into the energy program.

The primary savings and economic benefits have been directly related to the conversion and burning of wood in the various energy systems in the state. Other additional direct or indirect economical benefits are resulting in the use of wood for energy.

The poor quality stands now have a never-before existing market. This enables the landowner an opportunity to change his non-productive stand to a productive stand--one that will produce him an

income instead of an outlay in taxes. The wood energy concept can be utilized by foresters as a management tool to upgrade existing stands through timber stand improvement (TSI) or total tree harvesting, and replacing with a desirable species. By utilizing the total tree harvesting concept, reforestation costs can be reduced as compared to the intense site preparation following a conventional logging operation.

Georgia State University has estimated that for every 2,000 tons of wood chips used for fuel in the state that one permanent job is created in the job market, be it directly or indirectly related; i.e. boiler operator or secretary hired to handle the paperwork.

The combination of the forest products industry, non-forest related industries, state institutions and homeowners resulted in an estimated 13.1 million tons of wood used for energy in Georgia in 1981. The savings that resulted in the conversion from fuel oil to wood would be 495 million dollars annually. This, combined with other indirect economic benefits, contributed to over half-billion savings to Georgians. Wood energy is renewable, lessens the state's dependency on imported fuels, reduces fuel cost at various systems, keeps dollars in Georgia, creates jobs, and is enabling us to upgrade the existing stands to meet future demands being placed on forestry in Georgia.

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Entire Book

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A collection of 15 papers describing research on the measurement, harvesting and utilization of forest biomass, and a discussion of policies guiding the use of forest biomass for energy.

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